PHYSIOLOGY.

VOL. I.

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OUTLINES

OF

PHYSIOLOGY

HUMAN AND COMPARATIVE.

BY

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IN TWO VOLUMES.

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Errata.

Page 236, line 25, *for* 180° *read* 108°.
Page 329, last line, *for* depend *read* depends.

PREFACE.

The plan of the present work has been designed with the special view to its utility as an Educational Book, the subject being explained, in it, in a particular order and manner, and the Science of Physiology treated as dependent on those of Anatomy, Chemistry, and Physics.

In completing the details of each subject, the best and most recent authorities have been consulted, especially the systematic works of Quain and Sharpey, Gray, Kölliker, Gegenbauer, and Leydig, on Anatomy, and of Carpenter, Todd and Bowman, Müller, and Vierordt, on Physiology. Besides this, many of the articles in Todd's Cyclopædia of Anatomy and Physiology, and many separate works or essays have been referred to, including Papers by Owen, Allen Thomson, Huxley, Beale, and Quatrefages on Anatomical subjects, the Chemical and Physical Essays of Graham, Williamson, Dalton, Helmholz, Playfair, Frankland, Stokes, and Bence Jones, and the Physiological writings of Brown-Séquard, Dubois-Reymond, Bishop, Paget, Savory, Richardson, Lister, and others.

The work, as originally planned, several years since, was of smaller size and humbler pretensions; but, as now completed, after considerable labour and in fulfilment of a task once begun, it will, it is hoped, prove serviceable to the student of Medicine and Surgery, presenting a concise but comprehensive summary of modern Physiological Science, both Human and Comparative.

It also offers, to all candidates in Natural Science Examinations, to Teachers in Schools where instruction in Physiology is given, and to the lover of Nature generally, a convenient guide, and an ample store of information, in their Physiological studies.

As Anatomy teaches us the Structure of an Organised Body, Organic Chemistry, its Chemical constitution, and Physics, its Physical Properties,—so Physiology instructs us in the Physical, Chemical, and Vital actions which occur in it, during Life. The last-named science therefore requires a certain acquaintance with the others.

The following Outlines of Physiology, accordingly, commence with a short description of the Human Body, its Cavities, and the Organs which they contain. It is then shown how a beginner in Physiological studies may be assisted in this part of the subject by the Dissection of an Animal.

Attention is next drawn to the Textures or Tissues of which he several parts or Organs of the body are composed. The tongue and larynx of the sheep are selected as convenient parts, to illustrate the General characters, Connections, and Uses of these Tissues. The Microscopic Structure of the Tissues in the Human Body, is then described ; and afterwards, their Physical properties and Chemical constitution.

Under the head of General Physiology, an account is given of the Vital Properties of the Tissues, and a general outline of the Functions of the living Animal Body.

The relations of Man with External Nature, are next considered, including a sketch of the Animal Kingdom to which Man belongs, and of the Types and Laws of Form, which it presents. To this is added a comparison of the Animal with the Vegetable Kingdom, and of both those Organic Kingdoms with the Inorganic Kingdom.

The Special Physiology of the several Animal Functions, is then examined in detail, commencing with those of Animal Life, in the following order :—

Animal Motion ; Movements generally ; Animal Mechanics ;

Locomotion on solids, in fluids, and in air; Prehension; Manipulation; Gesture; Voice, and Speech.

Sensation, the Regulation of Movement, and the Psychical Functions, or the Functions of the Nervous System. Treated as special subjects under this head, are Sensation generally, and its Modifications; viz. the Internal Sensations, such as Hunger, Thirst, Nausea, and Want of Breath; and the External Sensations, viz. Touch, Temperature, Taste, Smell, Hearing, and Sight.

The foregoing subjects occupy the First Volume.

The Second Volume is devoted to the functions of Vegetative Life, as follows:—

Digestion, with an account of the Nature and Value of the different kinds of Food.

Absorption, including General Absorption, Absorption of the digested Food, and Interstitial Absorption.

The Circulation of the Blood, its Causes and Phenomena, and the Quantity of Blood in the Body.

Nutrition, both General and Reparative, of the Fluids and Solids of the body, with the Uses of the Blood, and its Vitality, the effects of Hæmorrhage, and the phenomenon of the Coagulation of the Blood.

Sanguification, or the processes by which the Blood is renewed. This includes an account of the Uses of the Ductless Glands, together with that of the Liver, considered as a Blood-Gland.

Secretion, or the processes by which certain Glands separate materials from the Blood, for use in the Living Economy.

Excretion, or the processes by which other Glands separate materials from the Blood, to be removed from the Economy.

Respiration, or the Function of Breathing, by which the Blood is purified, and the whole body maintained fit for the performance of all the Functions.

Animal Heat, Light, and Electricity, and their dependence on vita-Chemical action.

Animal Statics and Dynamics, treated of in a separate section, comprehending an account of the Specific Gravity,

the Stature, and the Weight of the body and its Organs; the balance between the Ingesta and the Egesta; the various Forms of Force or Energy exerted in the living body; and the Relations of these Forces to the quantity of Food and Air consumed, and to the Chemical Actions by which such Forces are produced.

The subject of Generation, includes a consideration of the different forms of Reproduction in the Animal Kingdom; the Development of the Vertebrate Embryo, its Appendages, Organs, and Tissues, and the mode of Reparation of the latter. The Evolution of the Chick is taken as the ground-work of the Description of the Embryo.

This Volume concludes with brief Sections on the Growth of the Body, its Decay and Death.

In treating each Function, the Structure and, where necessary, the Chemical Composition and Physical Properties of the several Organs, are described; and care is taken to indicate the Mechanical, Physical, and Chemical conditions, in harmony with, and frequently by the co-operation of, which they are performed.

At the end of each Section, the General or Essential Characters of a given Function, as distinguished from its Special Characters in Man, are illustrated by copious references to the Structure and Uses of the Organs concerned in that Function, in the several Classes of Animals.

The Author desires here to express his deep obligation to Mr. John Castaneda, for much valuable and prolonged assistance.

10, Savile Row,
Oct. 1867.

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ANATOMY.

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SPECIAL PHYSIOLOGY.

OUTLINES

OF

PHYSIOLOGY.

ANATOMY;

OR

THE LIFELESS BODY.

THE GENERAL PLAN OF THE BODY.

THE SKELETON.

The internal solid basis, or framework, of the Human body, like that of the bodies of all the Vertebrate Animals, consists of the *bones*,—which taken together constitute the *skeleton*, figs. 1 and 2.

The skeleton gives general form to the body, and determines its linear proportions. Like the entire body itself, it is easily subdivided into the Head, the Trunk, and the Limbs. In the natural state, the separate pieces of the skeleton are held together by strong flexible membranous bands, named *ligaments*, as represented on the left side of the figures.

The *head* consists of the smooth round part called the *cranium* or *skull proper*, and of an uneven part corresponding with the *face*,—the bone forming the *lower jaw* being the only movable piece in this portion of the skeleton.

The *trunk* is composed, first and fundamentally, of a strong median column, consisting of many bones, and occupying the middle line of the back, fig. 2. It bears the head upon its summit, and terminates in the soft parts below. It is called the *back bone*; also, from its numerous projections backwards, the *spine*, or the *spinal column*; and again, the *vertebral column*, because its numerous component pieces are named *vertebræ*, from *verto*, I turn,—each piece having a slight turning movement upon those next to it. The parts of the spine corresponding with the *neck* and *loins*, have no separate bony pieces attached

Fig. 1.

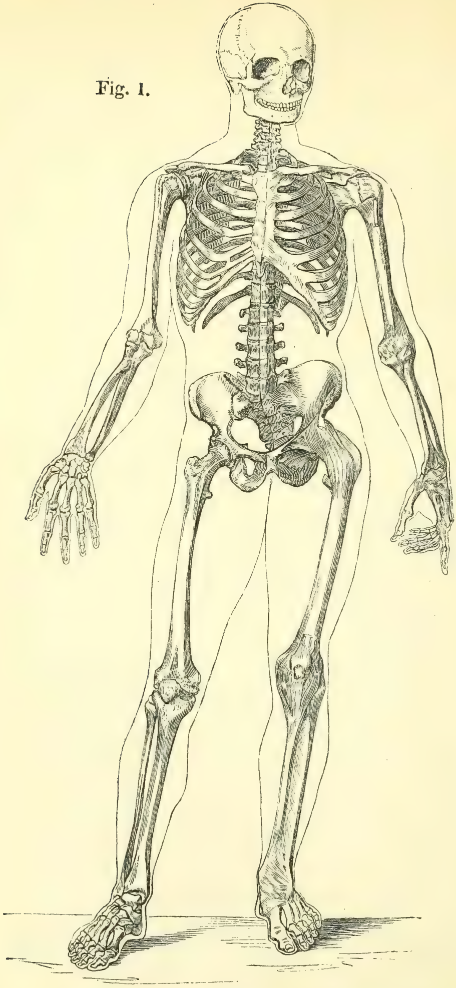
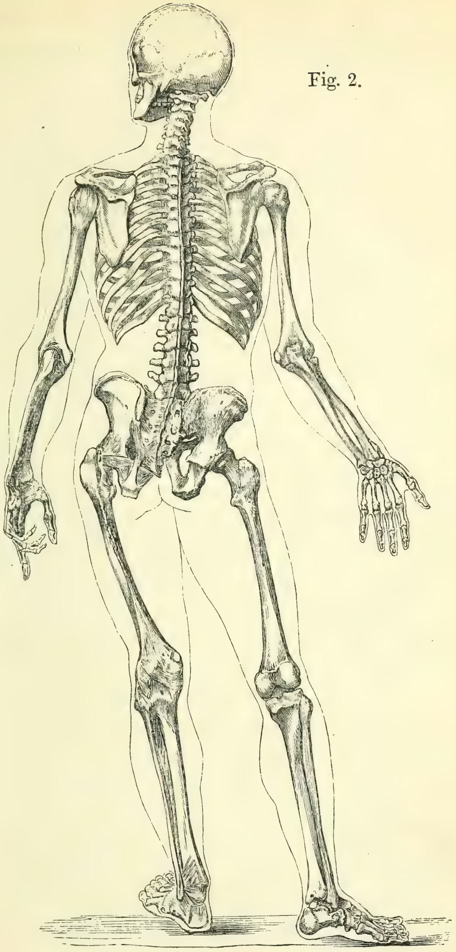


Fig. 1. A front view of the Human Skeleton,—the bones being surrounded with a contour outline, to show their position within the soft parts of the body. The bones of the left side and limbs are represented as if

Fig. 2.



held together by membranous structures at the joints. (*Bourgery and Jacob.*)

Fig. 2. The back view of the Human Skeleton. (*Bourgery and Jacob.*)

to them laterally; but in the intermediate part, corresponding with what is generally known as the *back* proper, those long slender curved bones called the *ribs* or *costæ*, are found fastened to it on either side, and passing forwards are prolonged in front by the *rib-cartilages*, the upper seven of which are joined to the *sternum* or *breast-bone* (fig. 1). Reaching outwards from the top of the breast-bone, on each side, to the shoulders, and placed horizontally across the root of the neck, are the *collar-bones*, so named because a collar worn round the neck rests upon them,—otherwise named the *clavicles*, from the diminutive of *clavis*, a key. To the outer end of each collar-bone, is attached the corresponding *shoulder-bone*, *blade-bone*, *spade-bone* or *scapula* (from *σκαπτω*, *scapto*, I dig). The two flat triangular-shaped *scapulæ*, placed at the back of the trunk, are thus suspended by the collar-bones, so as to be very movable. Broadly and strongly connected with the part of the vertebral column next below the loins, which is called the *sacrum*, or sacred bone, because this part in animals was offered in heathen sacrifices, are two wide bones, called the *hip-bones*, also the *innominate* or *un-named* bones (from *in*, not, and *nomen*, a name, because they had no special name). As shown in fig. 10, each consists of the *ilium*, *i*, the *ischium*, *is*, and the *pubes*, *p*. They are tied firmly together in front, and form, with the intervening sacrum behind, a strong hoop-like base to the trunk, named the *pelvis*, which means a *basin*.

Of the *limbs*,—the upper one, on each side, is connected to the comparatively movable scapula, whilst the lower limb is attached to the fixed hip-bone of its own side. The bones of the limbs obviously correspond with those natural subdivisions of arm, fore-arm, wrist and hand, and thigh, leg, ankle and foot. The arm-bone is called the *humerus*. Of the two bones of the fore-arm, the outer one, in a line with the thumb, is called the *radius* or *spoke-bone*, and the inner one, in a line with the little finger, the *ulna* or *elbow-bone*, or the *cubit*,—this measure being taken from the distance between the point of the elbow and the tip of the middle finger. The bones of the *wrist* or *carpus* (from *carpo*, I pluck), *eight* in number, are called the *carpal bones*; they are in two rows, viz. the *scaphoid*, *semilunar*, *cuboid* and *pisiform*, and the *trapezium*, *trapezoid*, *os magnum*, and *unciform bone*. Next to these, are five small long bones, called the *metacarpal bones* (*μετα*, *meta*, signifying with) which form the base of the thumb, and the broad part of the hand; and lastly, to these, succeed fourteen little bones, *two*

for the thumb, and *three* for each finger, named the *phalanges* (from *phalanx*, a row), of the fingers. In the lower limb, the *thigh-bone* is called the *femur.* The inner and larger of the two leg-bones, is named the *tibia*, or *shin-bone*, and the outer slender one, the *fibula* or *splint-bone* : the term *tibia* is taken from the resemblance of the bone to an ancient shepherd's pipe, and *fibula* means a *clasp* or *brace.* Succeeding to these bones, are *seven* short ones, named the *tarsal* bones, from *tarsus* the ankle; the one which is next to the leg-bone, is named the *astragalus* ; the large one below this, which projects to form the heel or calcaneum, is named the *os calcis*, or bone of the heel; in front of these, are the *cuboid* bone, on the outer side, and the *scaphoid*, with the three *cuneiform* bones, on the inner side. In front of these are, as in the hand, five bones, one for each toe, called the *metatarsal bones* ; and finally, to these are attached the fourteen *phalanges* of the toes, of which two only belong to the great toe (as in the thumb), and three to each of the other toes. There is an extra bone in the lower limb, in front of the knee-joint, called the *patella* or *knee-pan* : this, however, belongs properly to the muscular system, as we shall hereafter see. The same may be said of some little rounded bones, found in connection with certain muscles of the thumb and great toe, called *sesamoid* bones, from sesame, a grain of (Indian) corn. At the root of the tongue, is the *hyoid* bone.

Whilst contained within the body, all the bones are of course moist; they are also pinkish white, and they are covered with a tough semi-transparent closely adherent membrane, called the *periosteum.* The surfaces of the bones, are hard and *compact*; they are marked in places with little holes or pores, which lead into the interior of the bones, where we find, not a solid, but an open spongy-looking, or *cancellated* structure, the spaces or cells of which are occupied chiefly by a soft fatty tissue, called the *medulla*, or *marrow.*

On looking generally at the bones, it will be seen that to suit various purposes in the body, some of them are *broad* and *flat*, others *short* and thick, and, lastly, others *long* and comparatively slender.

THE JOINTS.

The places where the bones meet, and are joined together by membranes passing from one bone to another, are commonly known as the *joints*,—the connecting membranes being named the *ligaments*, from *ligo*, I tie. The different kinds

of joints will be hereafter studied in the Physiological part of this work, in the section on the *Movements* of Man and Animals. In most of them, the ends of the bones are beautifully fitted together, and covered with a thinnish layer of *gristle* or *cartilage*, a tough elastic substance, smooth on the free surface, and, moreover, moistened with a viscid fluid, improperly termed *joint-oil*, but named *synovia*, from its resemblance to the white of egg (*συν*, *sūn*, with, and *οον*, *oon*, an egg), which is contained in the cavities of the joints, and runs

Fig. 3.

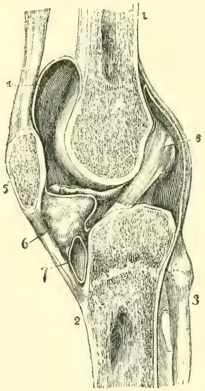


Fig. 3. Vertical section through the middle of the right knee-joint. It shows the cancellated or spongy texture of the lower end of the femur, 1, and upper end of the tibia, 2; also the thin layer of cartilage covering the ends of those bones. 3 is a part of the fibula. 4 is the cavity of the joint, made more apparent by separation of its naturally apposed surfaces, and lined by the synovial membrane. 5, section of the kneepan, also covered, next the joint, with cartilage. 6, a mass of fat, filling up intermediate space. 7, a separate synovial membrane, called a synovial bursa. 8, one of the ligaments, peculiar to the knee-joint, called the crucial ligaments. (*Bourgery.*)

out when these are opened by dividing the ligaments. The interior of the joints, excepting only the cartilages which cover the bones, is lined by a thin membrane, called a *synovial* membrane. These facts are illustrated in the annexed drawing of a section of the right knee-joint, fig. 3, to the separate description of which reference should now be made.

THE FLESH OR MUSCLES.

Covering up the bones generally, and attached to their surfaces at certain definite places, is the soft, red, fleshy, portion, or *muscular substance* of the body. This consists, not of one homogeneous environing mass, but of a great number (about 400) of distinct fleshy masses of various forms and sizes, which are called the *muscles*, figs. 4 and 5.

On consulting these figures, it will be seen that on the shape and disposition of the muscles, mainly depend the particular contours of the human body. The muscles will again be noticed, in the Section on the Movements of Man and Animals. In the meantime, it will be observed that they are arranged in *layers*, some *deeper* than others, and lying next to the bones, as seen in the left half of the trunk in fig. 4, and some more *superficial*, as shown on the right side of the trunk. It will be noticed that, on the trunk, the muscles are generally *broad*, and, on the limbs, *longer* and *narrower*. Many of the muscles are connected with the bones *directly*, by broad surfaces; but many are attached *indirectly*, by means of glistening *white* structures called *tendons*, which may be broad, short, and flat, as on the trunk, or long, narrow, and cord-like, as in the limbs. All the muscles of the body, are held together by an intermediate moist, and whitish, web-like structure, called *intermuscular areolar* tissue; sometimes a firmer membrane separates them, forming *intermuscular septa*; and most of them, especially those of the limbs, are bound down by a general membranous investment, called the *fascia* (fig. 5, on the left limbs), which is thicker on the outer aspect of the limbs, and especially in the palms and in the soles, than elsewhere. This fascia is also shown in fig. 6.

THE INTEGUMENTS.

Outside the fascia, but connected with it, is a layer, or two, of loose web-like *areolar* tissue, containing in its meshes more or less fat; and outside this, again, and connected with it, is the *integument* or *skin*, which is thus held down to the fascia. The areolar tissue and the fat, are both called *subcutaneous* (*sub*, under, *cutis*, the skin). Together with the skin itself, they round off, fill up, and finish the contours of the whole surface of the body.

Fig. 4.

Fig. 4. A dissected view of the principal muscles of the Human body. On the left half of the trunk, the muscles which lie next upon the bones, are shown. On the right half, the superficial ones are represented. In the head, neck, and limbs, no muscles are removed. The narrow white cords connected with the muscles, are the tendons. (*Bourgery and Jacob.*)

Fig. 5.

Fig. 5. A dissected view of the muscles found on the back of the Human body, and on the posterior aspect of the limbs. In the case of the left limbs, the membranous expansion called the fascia, which immediately invests the muscles, is supposed to remain upon them; whilst in the right limbs, it is removed. (*Bourgery and Jacob.*)

Fig. 6.

Fig. 6. A superficial dissected view of the left arm—the skin, and subcutaneous fat and areolar tissue having been removed. It shows the fascia, or membrane, which invests the muscles and their tendons; it also displays the superficial, or subcutaneous, veins 1, 1, and nerves,—the former being shaded, and the latter left as white cords. (*After Bourgery.*)

Fig. 7.

Fig. 7. A deep dissected view of the left upper limb,—the fascia having been removed, and some of the muscles taken away, so as to show the main arteries of the limb (here shaded with cross lines), 1, and the deep-seated nerves, (left as white cords), 2, 3, 4. (*After Quain.*)

THE VESSELS AND NERVES.

Coursing along in the subcutaneous areolar tissue, and therefore just beneath the skin, are certain delicate tubes and cords, called the *superficial vessels* and *nerves*, which in the limbs are found resting upon or outside the fascia, fig. 6. The vessels are of two kinds : — first, the *blood-vessels*, which convey the *blood*, namely, the *arteries*, not here represented, being comparatively small, and the *veins*, which are larger, and are shown as dark meandering lines ; and, secondly, there are the *absorbent vessels*, which convey a thin colourless fluid called *lymph*, and which are exceedingly delicate, and can only be demonstrated by consummate skill and the aid of mercurial injections : these absorbents have little bodies connected with them at the bendings of the great joints called the *absorbent glands*. The superficial nerves are delicate white cords, shown in the figure as white lines; they are the *cutaneous nerves*, which perforate the fascia to reach the skin.

When the fascia is removed, and the muscles dissected out, and some of them cut away, the *deep blood-vessels* and *nerves* are brought into view, taking their course in the intervals between the muscles. They are connected by branches perforating the fascia with the superficial sets. In fig. 7 the main *arteries* of the upper limb are shown ; the *veins* are omitted for the sake of clearness; the deep nerves, or *muscular nerves*, belonging to the muscles are exhibited; the *deep absorbents* are so delicate as to be quite undemonstrable in so small a figure.

Such, then, are the parts to be found in the limbs, proceeding from within outwards, viz., the bones containing their marrow, and covered with the membranous periosteum ; the cartilages, ligaments, synovial membranes, and synovia of the joints; the muscles with their tendons; the intermuscular septa and areolar tissue, in which the deep absorbents, blood-vessels, and nerves are found proceeding to and from the muscles, bones, and joints; the fascia investing the muscles ; the subcutaneous areolar tissue and fat, containing the superficial blood-vessels, absorbents, and nerves belonging to the skin ; and, lastly, the skin itself.

The very same parts are also found in the head, and in the general framework of the trunk. But in these situations the skeleton not only constitutes a central axis or basis for the surrounding muscles and other soft parts, but some of its pieces

are so shaped, arranged, and held together as to enclose certain spaces or hollows, called the *cavities* of the body, in which those special parts of the system, called the *Organs* or *Viscera*, are lodged and protected.

THE CAVITIES OF THE BODY AND THEIR CONTAINED ORGANS.

Three great Cavities are formed in the framework of the body, viz., those of the Skull, the Chest, and the Abdomen. There is also a subordinate cavity within the spinal column, and several others in the face.

a. The cavity of the skull, shown cut through vertically in the middle line in fig. 9, has completely solid walls, formed of the united bones of the cranium. One of these bones, the *frontal*, fig. 8, 1, corresponds with the forepart of the head (the *frons*, *forehead*), and also forms the upper margin of the sockets for the eyes; two others, one on each side, 2, called the *parietal* bones (*paries*, the side), form the sides and top of

Fig. 8.

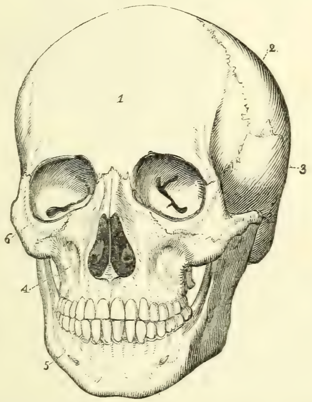


Fig. 8. The bones of the head, which consists of the cranium, and face; 1, frontal bone; 2, left parietal bone; 3, left temporal bone; 4, right upper jawbone; 5, lower jawbone; 6, right cheek-bone. This figure also shows the two eye-sockets or orbits, the opening leading into the right and left nasal or nose-cavities, and the arrangement of the teeth in the jawbones. The cranium has eight, and the face fourteen bones. (*From Nature.*)

the skull; other two, also existing in pairs, called the temporal bones, 3, correspond with the temples (*tempus*, time); another single bone, which forms the back of the head, is called the *occipital* bone (*ob* and *caput*, the head); and two other

Fig. 9.

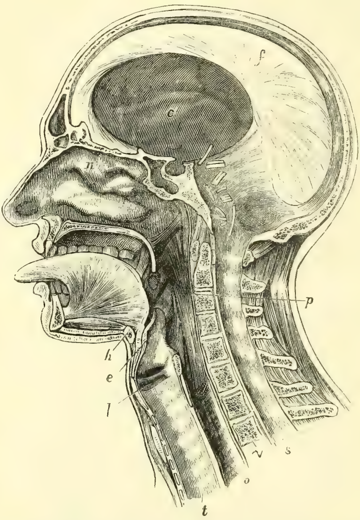


Fig. 9. A section vertically through the middle of the head and neck. The hollow of the skull, lined by the membranes called the dura mater and the arachnoid, is marked *c*. The membranous partition, called the falx, is marked *f;* its hinder part being connected below with the right half of the tentorium. The spinal canal, *s*, leading from the cranial cavity, is seen lower down still. The cut ends of certain cranial nerves are also shown. Along the upper edge of the falx, close to the bone, is a large channel or venous sinus. The sections of the cranial, facial, and spinal bones are also seen. The right nasal cavity is marked *n*. Below it is the cavity of the mouth, containing the tongue; — these two cavities are separated by the hard and soft palate. Both of them open behind into the throat cavity or pharynx, *p*, which again leads downwards into the gullet or œsophagus, *o*, immediately in front of the spine. At the root of the tongue is seen the cut surface, *h*, of the hyoid or lingual bone; suspended to this is the larynx, *l*, the hollow cartilaginous organ in which the voice is produced, and through which the air passes from the pharynx into the windpipe, *t*, which is the open tube running down the front of the neck from the larynx. The divided bodies of the vertebræ are marked *v*. (*After Bourgery.*)

single bones, viz., the *sphenoid* or wedge-shaped bone, and the *ethmoid* or sieve-like bone, complete the base or floor of the skull, which is also in part composed of the occipital and temporals. All these bones are joined together by their edges, which are unevenly toothed, or serrated, so that the lines by which they meet, called the *sutures* of the skull, are more or less uneven or zig-zag. It is also obvious that the walls of the skull are put together after the manner of an arch or vault. The cavity of the skull is lined throughout by a tough membrane, called the *dura mater*, fig. 9 *c* (hard mother), which acts as a sort of internal periosteum, and also smooths off the asperities of the bony surface. The dura mater also sends off a vertical partition downwards along the middle line, named, from its *sickle*-shape, the *falx*, *f*, which again falls behind on a transverse partition, called the *tentorium* or *tent*. The interior of the dura mater is everywhere lined by a very thin, smooth, and moist membrane, belonging to the *serous membranes*, and named the *arachnoid* (*αραχνη*, *arachne*, a spider). From the back part of the base of the skull there extends nearly the whole length down the centre of the spine or back bone, a secondary cavity, or rather a long canal, which is called the *spinal* or *vertebral canal*. The upper part of this canal, *s*, and its continuity with the cavity of the skull, which is effected through a large hole in the occipital bone, called the occipital *foramen* (or hole), are clearly seen in fig. 9. It is lined by a tubular extension of the dura mater, covered on its inner surface with the arachnoid membrane: the dura mater does *not* here attach itself closely to the bones, which have their proper periosteum distinct from it. The mode in which the bony canal is formed is this. The spine, as already stated, consists of a series of bones called vertebræ, arranged in form of a column. There are in the *neck* (cervix), fig. 10, 1, *seven* of these bones, called *cervical vertebræ;* in the *back* (dorsum), 2, *twelve dorsal vertebræ*, from * to *; in the *loins* (lumbi), 3, *five* lumbar vertebræ; making in all twenty-four *moveable* vertebræ. Next below these are five *sacral* vertebræ, consolidated into the one mass called the sacrum, 4; and below this are three or four little bones, called the *coccygeal* vertebræ, 5, forming the *coccyx* (cuckoo's bill): these constitute the *immoveable* vertebræ. It should also be here stated that the bones of the head are considered as consisting of specially modified bony elements, called *cranial* vertebræ. Each of the vertebræ, as shown in fig. 11, in which *a*, *c*, and *e*, represent

the right side, and ***b d***, and *f*, the upper surface of a characteristic cervical, dorsal, and lumbar vertebra, consists of a solid part called the *body*, which is turned forwards, and

Fig. 10.

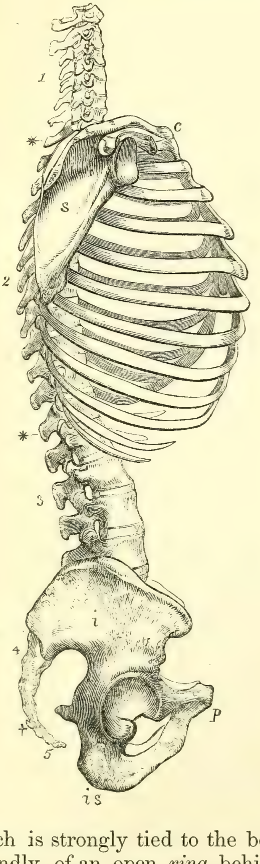


Fig. 10. Right side of the bones of the trunk. 1 to 5 is the spinal column; 1, the cervix or neck, consisting of seven cervical vertebræ. 2, from * to *, the dorsum or back, consisting of twelve dorsal vertebræ; 3, the loins, consisting of five lumbar vertebræ; 4, the sacrum, composed of five consolidated sacral vertebræ; and 5, the three or four imperfect vertebræ called coccygeal. The twelve ribs of the right side are also seen; and the inner side of the sternum in front. The right collar bone is marked *c;* the right scapula *s*. The right hip-bone, or innominate bone, is indicated by three letters: *i* on the part called the ilium, *is* on the ischium, and *p* on the pubes. The large rounded deep hollow cup where these three parts meet, is the acetabulum or socket for the head of the thigh bone; it contrasts with the small, oval, shallow depression in the scapula, named the glenoid cavity, intended for the reception of the humerus. (*From Nature.*)

which is strongly tied to the bodies of the adjacent vertebræ; secondly, of an open *ring* behind this; and thirdly, of three principal projections or processes, one backwards, called the

pinous process, from the whole series of which the backbone s called the spine, and two lateral ones called the *transverse* rocesses; there are also four other shorter processes on each noveable vertebra, two above and two below, called the *arti-ular* processes (*articulum*, a little joint), by which the several ones are still further joined together. The only part which

Fig. 11.

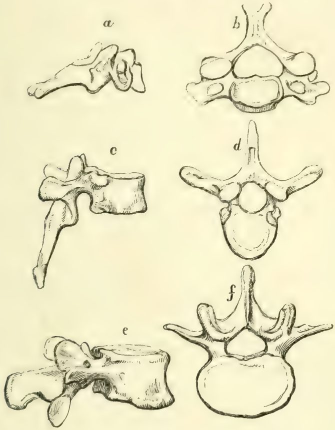


Fig. 11. Two different views of a characteristic cervical, a dorsal, and a lumbar vertebra. *a*, right side, and *b*, upper surface of a middle cervical vertebra; *c* and *d*, similar aspects of a middle dorsal vertebra; and *e* and *f*, the same of a middle lumbar vertebra. These figures show the thick or anterior part or body of the bones, their rings, their backward or spinous processes, their lateral or transverse processes, and their articular processes. The differences in size and form between each of these parts in the different vertebræ are also shown. (*From Nature.*)

ıow concerns us is the open vertebral ring: in the natural state t is the succession of these rings which forms the spinal canal, ig. 12, *c*, *e*.

Now, the cavity of the skull contains the large, soft, pulpy rgan called the *brain*, which is itself composed of the *cere-rum*, or *brain proper*, fig. 12, *a*, and the *cerebellum*, or *little rain*, *b*. The cerebrum and cerebellum are connected toge-her at the under part or *base of the brain;* but, above, the

cerebrum is parted into two lateral halves or *hemispheres*, whicl are lodged one on each side of the falx, whilst, below, th tentorium separates the cerebrum from the cerebellum. Th mechanical support thus afforded by the tentorium and th falx is obvious enough. From the base of the brain there i sent down a thick, white, stalk-like prolongation into the spi nal canal, which is named the *spinal cord*, *c*. It extends dowı only to the first lumbar vertebra, *c′*. The brain and spina cord are the *great centres* of the nervous system. Fron the base of the former, and from the sides of the latter (se fig. 62), are given off the white cords, called *nerves*, which passing through special openings in the base of the skull (se the cut ends of several in fig. 9), or through the *intervertebra* apertures between the vertebræ (see fig. 10, especially in th loins), branch out into every part of the body — (see fig. 64) The nerves form the *peripheral* part of the nervous system The brain and spinal cord are closely invested by a vasculaı membrane, the *pia mater*, over which is a layer of the arach-noid continuous along the roots of the nerves with that lining the dura mater.

The part of the entire skull which we call the face also has certain hollows or recesses in it, which may be regarded here as *cavities* for the lodgment of organs. Of the bones which are consolidated together below the cranium to form the face, some are seen on the surface, viz., the *cheek*-bones, fig. 8, 6, oı *malar* bones (*malæ*, the cheeks), which assist in forming the margins of the eye-sockets; the two upper jaw-bones, 4, oı *superior maxillary* bones (*maxillæ*, the jaws), which, together, contain the upper teeth, form the sides of a great notch which corresponds with the nose, and also ascend to complete the margins of the eye-sockets; the two little *nasal* bones (*nas*, the nose), which complete the upper boundary of the nasal cavities, and form the bridge of the nose; and, lastly, the lower jaw-bone, or *inferior maxillary* bone, 5, a single strong bone, shaped like a horse-shoe with its ends turned up, which finishes the face below, and gives form to the chin. Other bones, such as two *palate* bones, which complete the hard palate, the *vomer* or *ploughshare* bone, the edge of which is seen in fig. 9, and which helps to part off the right from the left cavity of the nose, two twisted or *turbinated* bones within the nose, and the two little *lacrymal* bones in the orbits, also enter into the formation of the face. Like the cranial bones, those of the face, of course excepting the lower jaw, are joined

Fig. 12.

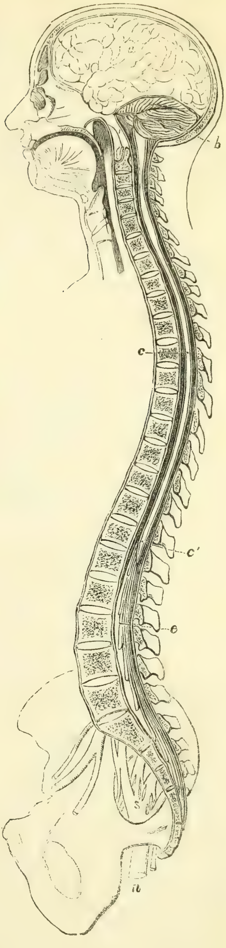


Fig. 12. A vertical median section through the cavity of the skull, and the spinal canal, to show the way in which the brain and its prolongation, the spinal cord, are lodged within the bony axis of the body. *a* is the cerebrum, or brain proper; *b* the cerebellum, or little brain; *c* the spinal canal; *c'* the lower end of the spinal cord; *e* the roots of the lumbar or sacral nerves, forming the cauda equina, or so-called horse's-tail; *s* the sacral plexus of nerves, and *n* the great sciatic nerve. This cut also shows sections of the bodies and rings of all the vertebræ; and of the nose, mouth, throat, gullet, tongue, larynx, and windpipe. The brain and spinal cord are protected from the bones by the dura mater, by two layers of the arachnoid, and by the inner membrane or pia mater. (*After Bourgery.*)

by sutures, but the lines of suture are more even than in the cranium.

The cavities of the face are these; first, the two *eye-sockets* or *orbits*, for the lodgment of the eyeballs, their muscles, vessels, and nerves, and of two little bodies called glands, which secrete or form the tears, — the *lacrymal glands* (*lacrymæ*, the tears); secondly, the *nasal cavities*, right and left, separated one from the other by a median partition, partly bony and partly cartilaginous, and from the mouth by the palate, but opening backwards, (as shown in the perfect state of the parts in fig. 9, in which *n* indicates the right nasal cavity,) into the upper part of the throat-cavity or pharynx, *p*, as well as forwards through the nostrils; thirdly, the cavity of the *mouth*, which also communicates with the pharynx, *p*, through the arched opening named the *fauces*, where the *tonsils* are seen at either side and the *uvula* in the middle; it contains, besides the tongue and teeth, two of the glands, named *sublingual* (*sub*, under, and *lingua*, the tongue), which secrete or form the saliva; lastly, there are certain small chambers, situated within the temporal bones, and communicating, at least in the dried state, with the exterior of the sides of the head, in which the apparatus of the internal ears is contained. We see, then, that the hollows of the face contain the various organs of the senses.

On the sides of the face and neck, behind and below the lower jaw, are four more salivary glands, two on each side, the *parotid* and *submaxillary* (see fig. 14), certain ducts or tubes from which convey the saliva which they secrete into the mouth.

In the *neck*, which is interposed between the head and the chest, there is no regularly defined and protected cavity, but certain important parts are found there, passing downwards from the pharynx, to reach the chest. Immediately beneath the root of the tongue, just at the re-entering angle of the neck, is situated the little *lingual* or *hyoid*, *i. e.* *v*-shaped bone, (shown in section at *h*, fig. 9,) which helps to support the tongue. Suspended to this hyoid bone, is a hollow cartilaginous organ, corresponding with the prominence of the throat, called the *larynx*, *l*. This is the organ of the voice; it communicates above with the pharynx, by means of a slit-like aperture, called the *glottis*, which is protected by a flap or valve, named the epiglottis, *e*; below, the larynx opens freely into the *wind-pipe* or *trachea*, which passes down into the chest, fig. 15, *t*, to branch into the lungs, and is known by

the numerous cartilaginous rings, which enter into its construction, and keep it constantly open. Behind the larynx, the pharynx, *p*, becomes continuous with a membranous tube, called the *gullet* or *œsophagus*, fig. 15, *o*, which also passes down behind the windpipe, and in front of the bodies of the cervical vertebræ into the chest, and thence on into the abdomen, to end in the stomach, as we shall presently see.

b. The *chest* or *thorax* is not, like the cranium, a complete osseous box, but rather an open cage-work of bones, consisting of the dorsal part of the spine, the twenty-four ribs, and the sternum, fig. 10, the intervals between which are occupied with muscles, membranes, vessels, and other soft parts. It therefore admits of certain essential alterations of its size. The thorax is conical in form, being narrowest above, where it is closed chiefly by the tubes and vessels passing into or out of it from or to the neck, and widest below, where it is separated from the other large cavity of the trunk,—the abdomen,—by a vaulted partition, partly muscular and partly tendinous, called the *diaphragm*, fig. 14, *d*, which springs from the spine, and is inserted into the lower borders of the cartilages of the seventh and the succeeding ribs, and into the tip of the sternum, all of which parts are represented as being preserved in fig. 13, to show the boundary between the opened chest and abdomen. The interior of the thorax is divided by membranes into three compartments: thus, on each side is a large compartment marked off and lined throughout by a thin, continuous, and moist *serous membrane*, called the *pleura*, which forms a completely closed sac, so that there are two *pleuræ*, or two distinct pleural sacs, one right and the other left. The right *lung* occupies the right pleural sac, and the left *lung* the left pleural sac, as may be seen in the annexed drawing, fig. 13. The cut edge of the right pleura is distinctly seen on the inner side of the right lung. The lungs, *l l*, are attached only at their roots, which are found at their posterior borders; everywhere else they are covered with a layer of their corresponding pleura, which is reflected upon them at their roots, so that each lung is really *outside* the sac of its pleura, the moist inner surfaces of which touch each other, — the lungs everywhere filling up their own compartments of the thorax. In the root of each lung is found a branch of the windpipe, certain large blood-vessels, other smaller ones, with absorbents and nerves.

Between the two pleural sacs is a space called the *mediastinum*, in which many parts are found. The chief of these is

Fig. 13.

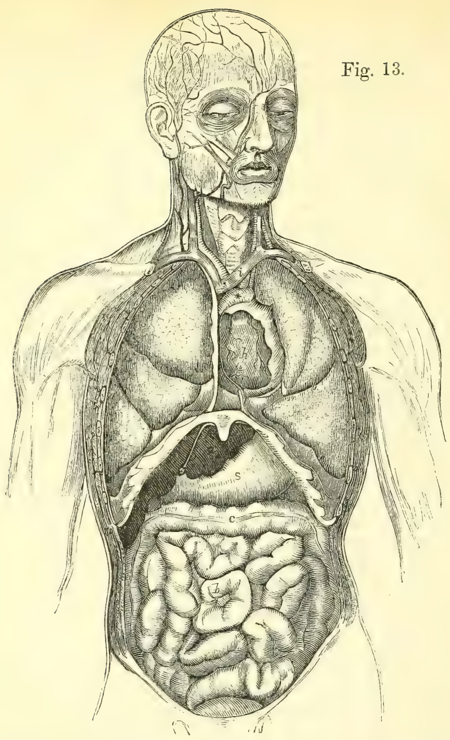


Fig. 13. Front view of the cavities of the thorax and abdomen, laid open by removal of their anterior walls. The tip of the sternum, and part of the cartilages of the seventh and following ribs, are preserved, as the diaphragm which separates these two large cavities of the trunk is fixed to them. In the thorax are seen the right and left lungs, *l l*, occupying each its own compartment; and between them, the pericardium, or bag of the heart, laid open to show a part of that organ, *h*. Passing up from the heart to the sides of the neck are the great blood-vessels, the aorta *, the vein *i*, between which are seen the windpipe, larynx, and pharynx. Below the diaphragm, and therefore in the abdomen, is seen, projecting below the right ribs, a part of the liver, *a*, crossed by a white line, which is the cut edge of its broad ligament: from a notch low down projects the gall-bladder. Under the liver, and to the left, is the stomach, *s*, at the left end of which is seen a piece of the spleen; below it is the transverse part of the great intestine, or transverse colon *c*, ending on the right side, below the liver, in the ascending colon, and on the left in the descending colon. Occupying the middle of the abdomen are the coils or convolutions of the small intestines. Lowest of all is the top of the urinary bladder. (*After Bourgery.*)

he *heart*, figs. 13 and 14 *h*. This organ is enclosed in a istinct fibrous bag or sac, lined by a smooth moist serous iembrane, and named the *pericardium*, the forepart of which s cut away in fig. 13, to show a portion of the heart, *h*. The eart, as seen in fig. 14 (in which both lungs are taken away), s attached above by the tubes or *great blood-vessels*, which pring from it, and branch out into all parts of the body. Of hese vessels there are two kinds, as already mentioned in decribing the blood-vessels of the limbs, viz., *arteries* and *veins*. 'he great artery, *p*, whose branches are distributed to the ings, is called the *pulmonary artery* (*pulmo*, the lung); the *ulmonary veins*, which proceed from the lungs to the heart, nter that organ behind, and are not seen in this figure. The sterisk * is placed on the *aorta*, the great arterial stem, from rhich all the arteries of the body are given off: their branches 1 the neck and elsewhere may be known by their being haded with cross lines: the continuation of the aorta in the bdomen, below the diaphragm, *d*, is also marked with an aserisk *. The great venous trunks, in which the veins of the ody ultimately end, are marked *v*, which indicates the *superior ena cava*, receiving the veins of the head, neck, chest-walls, nd upper limbs, and *v'*, placed on the *inferior vena cava*, reeiving the veins from the lower half of the trunk, and from ie lower limbs, and seen perforating the diaphragm *d*, to nter the heart. Thus attached, at its base only, by the aboveamed great blood-vessels, the heart projects forwards and to ie left side, so that its point or apex comes near the walls of ie chest, between the fifth and sixth ribs, a little to the left f the sternum. The sac of the pericardium, below, adheres) the diaphragm; at the base of the heart its fibrous layer dheres to the great blood-vessels, but its lining membrane or erous layer is reflected upon them, over the surface of the heart,) that this organ, like the lungs, is outside its serous sac, like man's head thrust into an old-fashioned double night-cap.

When the heart is removed, as in fig. 15, it is seen that esides the aorta, *a*, the thorax also contains the lower end f the trachea, or windpipe, *t*, which divides therein into wo chief branches, called the *bronchi*, which ultimately amify throughout the lungs, forming its innumerable *air-tubes* r *bronchial tubes* (see fig. 111). The thorax also contains he longest portion of the *gullet* or *œsophagus*, *o*, which is seen escending from the pharynx, *p*, supported all along upon the odies of the vertebræ, and which perforates the diaphragm to

Fig. 14.

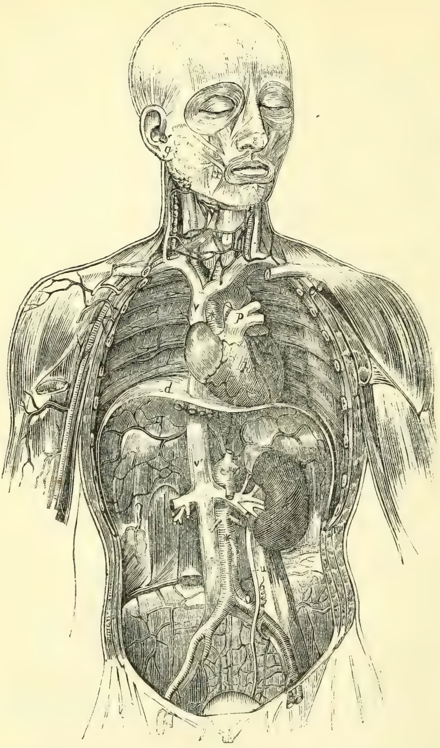


Fig. 14. Deeper view of the cavities of the thorax and abdomen, with most of their contents removed. In this figure the anterior half of the diaphragm is cut away. From the thorax, the lungs are removed; the pericardium is also dissected away from the heart, *h*, which is left attached to the great blood-vessels, of which *p* represents the pulmonary artery, * the aorta, and *v* the superior vena cava. The inferior vena cava, which is seen perforating the diaphragm, *d*, to reach the heart, is marked *v′*. The abdominal aorta is also marked with an asterisk *. The left kidney, *k*. is seen in its natural position, with its arteries and veins going into and out of it, also with its ureter or duct, *u*, leading down to the urinary bladder, which lies almost entirely concealcd in the pelvis. The left suprarenal body surmounts the kidney. (*After Bourgery.*)

enter the abdomen behind the liver, *l l′*, and end in the stomach, *s*. Besides these parts, there are found in the thorax, the principal *absorbent vessel* in the whole body, or main trunk of those vessels, called the *thoracic duct*, which, as shown in fig. 100, runs up through the thorax, from the abdomen into the neck, resting closely on the vertebral column. Lastly, the thorax also contains portions of the *sympathetic nerves*, and their branches. These, as shown hereafter in fig. 64, form a knotted cord on each side of the vertebral column.

But the chief contents of the thorax are the heart and lungs, the great central organs of circulation and respiration.

c. The *cavity of the abdomen* is even less protected by bones than that of the chest, being surrounded by soft parts only, such as broad muscles, tendons, fascia, and skin, excepting behind, where there is the lumbar portion of the spine, and below, where we find the pelvis, the cavity of which may be regarded here as supplementary to, as it is directly continuous with, the abdominal space. Above, the abdomen is as it were roofed in by the vaulted diaphragm, fig. 14, *d*. The capacity of the abdomen, as is needed for its contained organs, may vary very much.

Deeply seated in the abdomen are the great blood-vessels already mentioned, viz., the *abdominal aorta*,* and the *inferior vena cava*, *v′*, both giving off, of course, their numerous branches. Quite at the back of this cavity, corresponding with the region of the loins, on each side of the spine, are the two *kidneys*, of which the left one, seen in fig. 14, *k*, is placed rather higher than the other: from the inner border of each kidney descends a slender tube *u*, called the *ureter*, which descends into the pelvic cavity, and there opens into the *bladder*: at the top of each kidney is the *suprarenal body*. In front of the blood-vessels and kidneys, are found the essential organs of digestion, which indeed occupy nearly the whole abdomen. These consist, first, of the long membranous tube, constituting the abdominal portion of the *alimentary canal*, and, secondly, of certain accessory organs called *glands*.

When the anterior part of the walls of the abdomen is cut away, as in fig. 13, there is seen a small portion only of the large, dark red, firm glandular organ, called the *liver*, *a*, with the end of its little attached bag, named the *gall-bladder*, projecting from a notch in its lower border; there also comes into view the larger portion of the anterior surface of a dilated part of the alimentary canal called the *stomach*, *s*, and certain

Fig. 15.

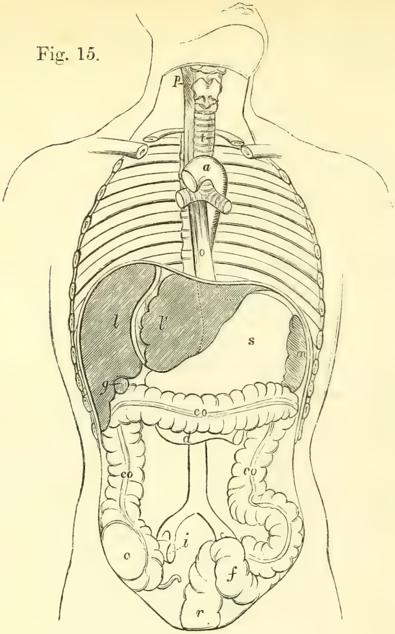


Fig. 15. The cavities of the thorax and abdomen, partly emptied of their contents. From the thorax, the lungs and their pleuræ, and the heart and pericardium, with most of the great blood-vessels, are taken away: there remain, the aorta or great artery of the body, *a;* the trachea or windpipe, branching below into the bronchi or air-tubes for the lungs, and ascending into the neck, *t*, where it is surmounted by the larynx; and lastly, the œsophagus or gullet, *o*, which is continuous in the neck with the pharynx, *p*, and in the abdomen, after passing through the arched diaphragm, and behind the liver, as shown by the dotted lines, with the stomach, *s*. From the abdomen nearly all of the small intestine has been removed. There is seen the dilated bag of the stomach, *s*, which receives the tubular œsophagus above, and opens below into the upper part of the small intestine named the duodenum, *d;* from this point to the short piece of the lower part of the small intestine named the ileum, marked *i*, the intestine is taken away. The commencement of the large intestine, called the cœcum, *c*, with its little appendix, is lodged above the right groin. Then follows the ascending, transverse, and descending colon, *co, co, co;* next the sigmoid flexure of the colon, *f*, and lastly the terminal part of the alimentary canal, named the rectum, *r*. In the middle line is seen the abdominal aorta, and its terminal branches. The two lobes of the liver are marked *l l';* between them is part of its broad ligament; *g*, is the gall-bladder; *m*, the spleen. (*A Plan.*)

ortions of the rest of the alimentary canal, namely, most of e coiled foldings or *convolutions* of the *small intestine*, *b*, urrounded on three sides by a part of the *great intestine*, *c*. upposing the thorax to be emptied, and the anterior half of e diaphragm to be cut away, as in fig. 15, then the liver, *l l′*, seen occupying the right upper part of the abdomen, close , and even suspended from, the under surface of the diaphragm; the end of the gall-bladder, *g*, is here also plainly sible. Partly covered by the liver, as shown by the dotted nes, is the stomach, *s*, with the lower end of the gullet, *o*, openg into it above; at the left end of the stomach and attached it is a dark purplish organ, *m*, named the *milt* or *spleen*. o the right, the stomach, or dilated part of the alimentary nal, curves downwards behind the transverse part of the eat intestine, *c o*, and opens into the commencement of the nall intestine, named the *duodenum*, *d*; the succeeding part the small intestine, named the *jejunum*, is here removed, nd so is the lower part named the *ileum*, except a short piece arked *i*; this part opens into the commencement of the large testine, which is named the *cœcum*, *c*, from which a little orm-like tube, called the *vermiform appendix*, proceeds. he cæcum is continuous with the next part of the large intesne, called the *colon*, which consists of four portions, named om their directions, the *ascending*, *transverse*, and *descending* olons, *co*, *co*, *co*, and the *sigmoid*, that is the *S-shaped flexure*, *f*, the colon. The remainder of the large intestine, *r*, the terinal portion of the alimentary canal, is named the *rectum*, om its comparatively straight course. If the liver, stomach, uodenum, and spleen be removed together from their position the abdomen, as in fig. 98, and if the liver, *l*, and stomach, be then turned up, so as better to show the duodenum, *d*, ere will then be seen stretching across from the curve of the uodenum on the right, to the spleen, *m*, on the left, a long nkish-white gland, very like a salivary gland, named the *ancreas*, *b*. It is further shown in this figure that the liver nd pancreas are provided with ducts, which open into the uodenum. The spleen has no duct; neither have the suprapnal bodies. In fig. 15, the pancreas is concealed by the ansverse colon and stomach.

Besides the various above-named parts and their proper ood-vessels, there also exist in the abdomen very numeris *absorbents*. Those belonging to the small intestine, named e *lacteals*, serve, as we shall hereafter see, a very special

office, and empty themselves into the commencement of the *thoracic duct*, which begins in the abdomen (see fig. 100). It remains to notice that the lower portions of the right and left *sympathetic nerves*, and their branches to the neighbouring viscera, are likewise contained in the abdominal and pelvic cavities.

There are no special or separate compartments in the abdominal cavity, as there are in the thorax; but the whole is lined by a single smooth, serous membrane, called the *peritonæum.* This membrane is also reflected on the stomach and intestines, reaching them from behind, along their blood-vessels, and serving to support them by folds called *mesenteries.* A large apron-like fold of the peritonæum, containing much fat, and named the *great omentum*, also hangs down from the stomach and transverse colon, over the small intestines, and doubtless serves to protect them and preserve their temperature: it is not shown in any of our figures. The peritonæum is also reflected on to the spleen and likewise from the diaphragm over a great part of the liver, assisting to support it and to form its so-called *ligaments;* but the pancreas, and the kidneys and supra-renal bodies are altogether behind it.

DISSECTION OF AN ANIMAL.

There are many respects in which the preceding outline of the general plan of construction of the human body will be better understood, if the student at this stage procure and dissect the body of a dog or rabbit. The latter being more easily obtained is described here. Due allowance must of course be made for differences, not only in the size, but also in the form, colour, and strength of construction of the parts of the animal as compared with the human organs. The student will find the following course of dissection the most convenient and useful:—

Place the dead animal on its back, secure the legs, and then divide the skin only along a line reaching from beneath the chin to the lower part of the abdomen. In now reflecting the *skin*, by dissection, from the subjacent parts, the loose *subcutaneous areolar tissue*, containing in its areolæ or meshes more or less fat or *adipose tissue*, will be met with, and cut across. When the skin is reflected, say from off the right half of the body, the soft pinkish flesh will be visible through the thin, firm fibrous membrane called the *fascia;* which will be found easier to display on the limbs than elsewhere. The fascia being now removed by another step in the dissection (taking care that the knife be made to follow the direction of the fleshy bundles which are being exposed), the flesh itself, or muscular substance, is seen to be collected into masses, forming the so-called *muscles*, and separated from one another by loose areolar tissue, or by firmer membranes, called *intermuscular septa.* The muscles of the thigh and leg will be found the easiest to dissect. Some muscles will be seen to have direct and broad attachments to the skeleton, and others to be indirectly connected to the bones by either

road, or long and slender, whitish, inextensible cords called *tendons.* The latter are principally found in the limbs; one of the most remarkble being placed at the back of the leg, and connecting the muscles of the alf with the heelbone. In dissecting the muscles on the inner side of the high, the large bloodvessels proceeding out of the abdomen will be met vith,—being known, the *vein*, by its being a flaccid tube containing *blood*, nd the *artery* by its remaining open or gaping, if cut across. Near hese vessels, some slender white cords, which are *nerves*, may be etected; but the chief nerve of the thigh will be found at the back f that part of the lower limb, descending amongst the muscles into the am, or space at the back of the knee. *Absorbent vessels* also exist, but hey are much too minute and delicate to be detected except by the nost expert anatomist using very special means of research; the *aborbent glands* will probably also be overlooked, in the fat and cellular issue of the groin. The muscles and their tendons being now cleanly ut away from the side of the pelvis, and from the thigh and leg, the xposed *bones* are seen to be whitish, moist, though hard structures, overed closely with a tough membrane, the *periosteum*, portions of which nay be dissected or stripped off. The *joints* of the thigh and knee nay now be cleaned externally; and their *ligaments*, the fibrous bands vhich tie the respective bones together, may be examined. On cutting hrough the latter, the closed sacs, or cavities of the joints, will be pened, showing the articular ends of the bones, nicely modelled so as o fit together, and covered with closely adherent and beautifully smooth *artilage*, the whole moistened with the viscid fluid, *synovia*, secreted rom a thin *synovial* membrane which covers the interior of the joint, xcepting the cartilages. After this, the thigh bone may be cut or roken across, or lengthways, to show the outer, dense, or *compact* layer, nd the inner, open, or *cancellated structure*, of which the bones are omposed, and also the soft, vascular, and fatty tissue, called the *marrow*, ound in the cells of the latter. The upper limbs, with their muscles, hich need not be specially dissected, may next be partially detached om the sides of the trunk, and reflected outwards.

It will now be observed, both by the aid of sight and touch, that hilst the forepart of the trunk is ribbed at the sides and front, the inder part has soft walls. The ribbed part is the *thorax*, the soft art the *abdomen*. These two cavities should then be opened, much fter the manner represented in regard to the human body in fig. 13. o open the thorax, the ribs and their attached muscles should be first ut through down each side of the chest; then the lowest cut rib, say n the left side, should be traced forward, detached from the soft parts elow it, and once more cut across upwards, near its anterior end; then e next ribs in succession upwards, with the intervening muscles, must e cut in the same way, until the lower end of the sternum is reached, hen that too is to be cut across: the same is to be done on the right de. The bony and muscular flap thus formed, consisting of the sterum or breastbone, and of the attached portions of ribs, is next to be ulled upwards, and forcibly detached, or cut away from the parts eneath it, being raised up as high as the neck, and then removed ntirely; at this step, the windpipe and great vessels should be felt or ooked for, and certain muscles which cover them may be lifted upwards s high as they ascend in the neck and cut away. To open the abdo-

men, an incision may be first made through its membranous and muscular walls along the middle line; two semilunar cuts, sweeping round, one on each side, and following, first the lower borders of the ribs, then the sides of the abdomen, and then the upper margin of the pelvis, will circumscribe the entire soft front of the abdominal walls, which may then be lifted up, and detached by severing the remains of a sort of band, or *peritonæal fold*, which is one of the supports or *ligaments* of *the liver.* The *diaphragm* will be seen separating the chest from the abdomen.

In the cavity of the abdomen, after noticing the general smoothness of its lining membrane, or *peritonæum*, there will first be observed the *great omentum*, an apron-like peritonæal fold containing little masses of fat: this may be lifted upwards and cut close along its upper margin: the *small intestine* will thus be exposed. The *convolutions* or windings of this may next be traced downwards to its lower end, which will be found above the right groin, where, being first tied in two places about an inch apart, it may be cut across between the strings. The small intestine itself is now to be removed by cutting, from below upwards, through the peritoneal fold, called the *mesentery*, which holds it to the back of the abdomen, and in which the bloodvessels, absorbents or lacteals, and nerves of the intestine are supported; on reaching the more fixed upper part of the small intestine, it is again to be tied in two places and cut through; by which step, the detached part, consisting of the *jejunum* and *ileum*, may be entirely removed. The *large intestine* may now be traced, ascending along the right side, passing next across, descending along the left side, and then entering the pelvis. Its commencement is named the *cæcum*, and from this it will be found there proceeds an enormous blind-ended, spirally-marked tube or cul-de-sac, which is a highly developed cæcal appendage, and is represented by the little *vermiform appendix* only, in the human body; to this succeeds the *ascending*, *transverse*, and *descending colon*, the *sigmoid flexure* of the colon, and lastly, the *rectum*. The rectum being twice tied and cut across, the whole of the large intestine is to be removed. The solid reddish organ, *the liver*, with its bright green *gall-bladder*, may now be examined; also the mode in which it fits up against the vault of the diaphragm, the way in which it is suspended to that structure, and the fact that it overlaps the stomach; it must be noted that it is much more deeply notched or divided than the human liver: it is to be drawn downwards and cut away by dividing the soft parts close to its surface all round. The *stomach*, known by its dilated form, but unlike the human stomach, marked off by a constriction into two parts, may now be examined; its connection above with the *gullet* may be determined by pulling upon it, or by pouring water, or passing a quill down the throat until it enters the stomach; its connection below with the *duodenum* should then be followed. The white glandular organ called the *pancreas*, or sweetbread, may next be traced, attached to the bent part of the duodenum, and reaching across to the left; and lastly the dark purplish organ called the *milt* or *spleen* will be found attached to the left side of the stomach itself. The gullet being now tied below the diaphragm, all these parts should be removed; when the two *kidneys*, more rounded than in man, with the *suprarenal bodies* surmounting them, their ducts or *ureters* leading from them, and the great *bloodvessels* in the middle line, viz., the abdominal *aorta* and the *inferior*

na cava, will come into view. The knotted cords of the *sympathetic* *rve* will also be seen.

In the thorax, the *two* lateral compartments formed by the right and ft smooth-surfaced *pleuræ* will be immediately observed, each conining its own *lung*, which light pinkish-white spongy organs will be und to have shrunk a little so as no longer to fill their respective eural sacs; at the back part of each lung its attached portion or *root* ill be discovered, upon which the pleura passes to cover the lung itself. y pulling on the roots of the lungs, their connection with the windpipe easily proved, as that part is seen to move accordingly. Air should lso be blown down through a glass tube into the windpipe, by which eans the lungs will be instantly inflated. Between the two lungs and artly overlapped by them, is the *pericardium*, the bag or sac in which e heart is contained: this must be opened, to show the heart in its atural position, having its free point or apex turned towards the ibs, and its broad attached base directed towards the back. The ericardium may now be snipped away from the diaphragm, and also om the great bloodvessels, which are seen springing from the base of he heart, and passing upwards to the neck, and sideways to the roots f the lungs. The great bloodvessels at the root of the neck, branchig some to the head, and others to the upper limbs, may next be ivided, together with the windpipe, and then all these parts, with the eart and lungs, may be stripped off downwards: on being laid upon board and examined from behind, the course of the *trachea* or *windipe* and its two *branches* or *bronchi*, as they go to the lungs may be istinctly traced. There remain in the thorax itself, the thoracic portions f the aorta and the gullet, the course of which last, from the neck own through the diaphragm, may be again demonstrated by aid of a uill. The diaphragm itself may now also be studied. It is useless o search for the *thoracic duct*, which however lies behind the gullet, pon the vertebral column. With care, the knotted cords of the *symathetic nerves* may be found, one at each side of the spine.

The upper remaining portion of the windpipe may next be traced up o the cartilaginous box, called the *larynx*, and the gullet up to the *phaynx*. At the side of the face and neck, just between the lower jaw nd the ear, will be found the principal *salivary gland*, called the *arotid* gland; another, the *submaxillary*, lies below the jaw in the eck. The lower jaw-bone may now be split or cut through in the midle line, and its right half detached from the parts beneath and taken way at the joint near the ear: this opens one side of the mouth, and harynx; and the opening thus made should be extended down the ullet. The tongue with the *sublingual* glands being drawn aside, the lit-like aperture, called the *glottis*, which leads into the larynx and so nto the windpipe, is seen; and also a small valve, called the *epiglottis*, vhich falls back from the root of the tongue over this opening. A uill passed backwards through each nostril will show the communiation of the *nasal cavities* with the upper part of the pharynx. The *ar* should be removed as close as possible to the head, to show the *passage* leading into the temporal bone, which contains the *internal* chambers of the *ear*. The *eyelids* may be divided at their outer corner and reflected back, to show the position of the *eyeball*, with its muscles and stalk-like nerve, lodged in the *eyesocket* or *orbit*.

The cranium should now be opened by a transverse saw cut made carefully through the *bone* only, above the orbits, met by two others running back to the occipital foramen. The top of the skull thus separated is to be raised up in front by a blunt chisel, and pulled off forcibly backwards. The *dura mater* thus exposed is, with its smooth *arachnoid* lining, to be cut along the same line as the bones, raised up and snipped away. The soft pulpy *brain*, much smaller, and more pointed in front, than the human brain, and nearly smooth as compared with that (see figs. 58 and 59), is then to be removed by being raised up in front, certain bloodvessels and all the nerves given off from its under surface being divided one by one, as they pass to their respective openings in the base of the skull: last of all, the thick prolongation from the base of the brain, down the spinal canal, called the *spinal cord*, will require to be cut across. The distinction between the *cerebrum* and *cerebellum* having been noticed, and the layer of *arachnoid* with the subjacent vascular *pia mater* still covering their surfaces,—the course of the spinal cord down the backbone may be either traced by cutting open the vertebral canal (a very difficult task), or a fine twig or wire may be thrust down to demonstrate the existence of the canal. It is from the sides of the spinal cord that the nerves of the walls of the trunk, and the nerves of the limbs are given off.

The practical information obtained by such an examination of the various organs in the body of a dog or rabbit, as is above prescribed, must now be transferred, as it were, to the study of the human organism. Beside those marked differences in the configuration of certain parts which have been incidentally mentioned, and others which will be obvious enough, it must by no means be forgotten that the muscles are paler, and their tissue softer, and that the intermediate areolar tissue, the ligaments, bloodvessels, and nerves, being on a smaller scale, have an apparently finer structure, than in man.

To guard against any misconceptions, or any confusion between the characters of the organs in the animal and in man, it will be well, at this stage, to re-peruse the previously given description and the woodcuts of the organs of the Human Body.

THE TEXTURES OF THE BODY.

GENERAL CONSIDERATIONS.

The different organs of the body, which we have now examined generally, are no more composed each of a uniform homogeneous material than is the body itself. On the contrary, every organ is built up of several very distinct elements which are called *Textures* or *Tissues*.

Thus, the heart, which speaking in general terms is said to be a hollow *muscular organ*, is really composed of the following parts. Externally, we find a thin reflected layer of the *serous membrane* called the pericardium, which itself consists of a

basis or web of dense *areolar connective tissue*, covered with a stratum of *epithelial tissue ;* next beneath this is the proper substance or striped *muscular tissue* of the heart, which is mixed with a very minute quantity of fine areolar tissue ; deeply seated in the interior of the heart, are certain rings, cords and valves or flaps composed of *fibrous connective tissue ;* and the internal surfaces of its cavities are lined with a thin smooth membrane, named the *endocardium*, which is like a serous membrane in its nature, being composed of a very fine layer of *areolar connective tissue* covered with a very delicate *epithelium.* Besides this, the heart has its proper *bloodvessels* and *absorbents*, all of which have their component tissues, viz., *areolar*, *elastic*, *unstriped muscular*, and *epithelial tissues.* Lastly there are the *nerves* and *ganglia*, which consist of the *nervous tissues*, supported by sheaths of *areolar connective tissue.* So on of all the organs in the body.

Of late years, under the name first of General Anatomy, and, now, of *Histology* (*ιστος*, *histos*, a web, and *λογος*, *logos*, a discourse), these tissues or textures have been very minutely studied by aid of the microscope and certain chemical re-agents; and it is truly remarkable what a variety of beautifully adapted minute elementary tissues have thus been discriminated both in animal and in vegetable organisms.

TEXTURES IN THE TONGUE AND LARYNX OF A SHEEP.

The tongue, larynx and upper portion of the trachea or windpipe of a sheep, attached to a piece of the middle of the lower jaw-bone, being obtained from a butcher, a dissection like that represented in fig. 16 may be readily made with a little care, the parts being first fixed with strong pins upon a piece of board, and then portions being removed from the right side of the organ. Examples of every kind of tissue will be met with in such a dissection; and, from it, as the tissues of the sheep more nearly resemble the human textures than those of the rabbit, their naked eye appearances, their mutual relations, and their adaptation to particular purposes will be better understood, preparatory to studying their microscopic characters in the human frame.

The solid walls of the larynx, *c*, and also the firm rings which nearly surround the trachea, afford an example of one variety of that white semi-opaque firm elastic substance called *cartilage* or *gristle.* Parallel with the upper border of the larynx are the several pieces of the lingual or hyoid bone, which is large in the sheep, and presents us with an illustration of *osseous tissue*, which however is better exemplified in the lower jaw, *b*. Both the cartilages and the bones are covered with a so-called *fibrous membrane* composed of *fibrous connective tissue* named in the former case the *perichondrium*, and in the latter the *periosteum*, *p.*

Fig. 16.

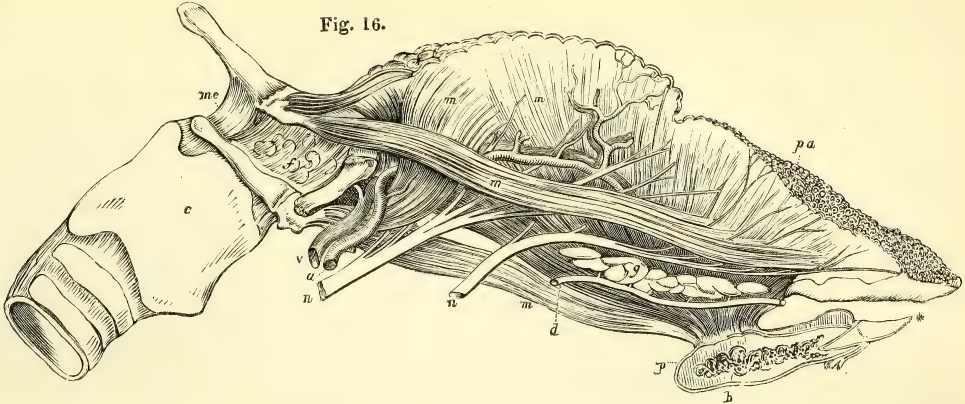


Fig. 16. A view of the right side of the tongue, larynx, and two upper rings of the trachea or windpipe of the sheep, attached to a piece of the lower jaw; the whole being dissected to show its constituent parts. *c*, the thyroid cartilage of the larynx: below this are two cartilaginous rings of the trachea, all being held together by intermediate membrane. Above the larynx are the several pieces of the hyoid bone and its adjuncts. *me* is a simple membrane, containing little lobules of fat, *f*. *m*, *m*, *m*, are various muscles of the tongue. *pa* is the papillary mucous membrane by which it is covered. *a* is the lingual artery entering the tongue, and *v*, the lingual vein passing out of it; the branches of both vessels are seen in the substance of the organ. *n* (to the left) is the hypoglossal nerve, the muscular or motor nerve of the tongue; *n* (to the right) is the lingual branch of the fifth nerve, going to the mucous membrane, and constituting the sensory nerve of the tip of the tongue. *g* is the sublingual gland, one of the salivary glands, the ducts of which end in the larger duct, *d*, of the submaxillary gland, which is not seen here. The duct *d*, opens into the mouth, beneath the tip of the tongue. *b* is the section of the lower jawbone, showing the cancellated structure, and containing one of the incisor teeth. *p* is the periosteum, covering that bone. (The Author.)

In the open or cancellated structure of the jaw-bone, will be found some *marrow*. The tooth furnishes us with an example of *tooth-substance*, or *dentine*, of the *crusta petrosa*, and of the hard pearly *enamel* by which its smooth exposed part is covered. The rings of the trachea, the larynx, and the pieces of the hyoid bone are connected together by simple *membrane*, of which the piece marked, *m*, is a good illustration, consisting of dense *areolar connective* tissue; in it will be found examples of the little lobulated masses of *adipose tissue* or fat, *f*. Plenty of the loose form of *areolar connective* tissue is also found (in many places charged with fat), connecting the different parts, and surrounding and supporting them. In the junctions of the several pieces of the larynx, (to be exposed by dissecting the piece, *c*, away from the rest) little joints even will be detected, united by *ligaments* composed of *fibrous connective* tissue, and lined by *synovial membranes*, consisting of a basis of *areolar connective tissue*, covered by a layer of *epithelium*. On examining the interior of the larynx, it will be found that the slit-like opening called the *glottis* is bounded on each side by two yellowish looking cords, the *vocal cords:* these are composed of nearly pure *yellow elastic tissue*. The valve at the root of the tongue, called the *epiglottis*, which projects over the aperture of the glottis, is made up of a mixture of *cartilage* and *elastic tissue*, or *yellow fibro-cartilage*.

Situated in the substance of the membrane composing the hinder flattened part of the trachea, where the rings do not reach, are transverse bands of a pale pinkish hue: these consist of the *unstriped* or simplest form of *muscular tissue*, such as is found in the viscera generally, excepting only the heart. The mass of the tongue consists of the *striped form* of *muscular* tissue, such as constitutes the flesh or muscles generally. As shown in the dissection, this striped muscular tissue is composed of bundles of soft fibres, which are collected into definite masses, or *muscles*, such as are marked, *m*, *m*, *m*, one radiating from the lower jaw throughout the whole tongue, another passing from the lower jaw to the hyoid bone, and others passing in form of three bundles from various points of the hyoid bony apparatus to different parts of the tongue,—one reaching to its very tip.

Entering the tongue at its side near the root is one of those blood-vessels which are called *arteries*, *a ;* and passing out from the tongue near it is a *vein*, *v ;* the branches of both being traceable far into the tongue, where they finally end in a common uniting network of those minute vessels, invisible to the naked eye, named *capillaries*. All the *blood* of the tongue in the natural state is contained within these three kinds of tubes or vessels. There are also *absorbents* belonging to the tongue, but these it is impossible to see. Two *nerves*, *n*, *n*, likewise penetrate the tongue, one of which, the hinder one, sends its fine branches into the muscular substance, being a muscular nerve; whilst the other, the forward one, gives off twigs which advance through the muscular substance to the surface of the organ, and supply the soft moist *membrane* or skin which everywhere covers it in the natural condition.

This membrane or skin is a *mucous membrane*. It is indeed only a part of that extensive mucous membrane which, commencing at the mouth and nostrils, passes from both points backwards into the pharynx, and thence into the larynx, and along the windpipe and its branches into every part of the lungs, and also down the gullet, along through

the stomach and the rest of the alimentary canal. On the under side of the free part of the tongue, where it is continuous with the gums, this covering membrane is *smooth*, but on the fore part on the top of the tongue, *pa*, it is covered with little eminences called *papillæ*, or is papillated; further back it has larger papillæ, and is also provided with *mucous follicles* and *glands*, — little organs which secrete or form the *mucus* or general moisture of the mouth. The *saliva* is formed by more complex *secreting* glands, of which one called the *sublingual gland*, *g*, is shown in the dissection. It is a lobulated mass from which many short tubes or *ducts* proceed and enter a larger tube or *duct*, *d*, beneath, which comes itself from the submaxillary gland, not shown in the figure, and opens on to the surface of the mucous membrane beneath the fore-part of the tongue, where it discharges its salivary secretion or saliva into the mouth. These and all other *secreting glands*, as we shall hereafter see, are but appendages or extensions of the mucous membrane, which is prolonged into their ducts. The mucous membrane of the tongue is formed of a layer of condensed *areolar connective tissue* covered by an *epithelium*. Its epithelium is of the kind called *squamous*. The epithelium covering the mucous membrane of the interior of the larynx and windpipe is *columnar* and *ciliated*, i. e. provided with microscopic lash-like moving organs called *cilia*.

The tissues thus enumerated and demonstrated from the sheep's tongue and larynx may even be used for microscopical examination to illustrate the descriptions now to be given of the human tissues. A few special tissues, such as the brain substance, the substance of peculiar glands, and the parts of the organs of the senses, as well as pure articular cartilage, and white fibro-cartilage, may be taken also from the sheep. There is, however, no skin like the human skin.

In examining the tissues microscopically a common watchmaker's lens may be first employed upon them. Afterwards those tissues which are composed of filamentous or tubular elements may be prepared for the compound microscope by pulling or tearing asunder by means of needles, the constituent parts of a small portion, the size of a pin's head, placed in a drop or two of water on a piece of glass. Of the solid tissues a very thin section must be made, and put on glass in a drop of water. Thus prepared the specimens must be covered with the fine glass sold for that purpose, and then they may be examined under the compound microscope as transparent objects. The epithelial coverings of membranes merely require to be scraped off and moistened with a drop of water. Various reagents are employed to alter the tissues under examination, as will be mentioned hereafter. The order in which the several tissues will now be described is one of convenience only. The mode in which they may be classified will be stated in the physiological section of the work.

THE MICROSCOPIC STRUCTURE OF THE TISSUES OF THE HUMAN BODY.

Connective tissue.—This tissue exists in two forms, *areolar* and *fibrous*. The *areolar* form connects organs and parts of organs together, supports their vessels and nerves, and allows of

a certain movement amongst them; it consists of a loose moist extensible web, composed of interlacing bundles and bands, having intervals between them called *areolæ* or *cells*, whence it is named also *cellular tissue.* These areolæ communicate through the whole body, and are the spaces in which the fat is lodged, and in which fluid collects in general dropsy. Under the skin, and the mucous and other membranes, the areolar connective tissue is named *subcutaneous*, *submucous*, and so on. In a more condensed form it constitutes the basis of those membranes themselves.

The bundles of this tissue are made up of delicate transparent colourless *filaments*, fig. 17, *a*, held together by moist homogeneous matter. The filaments are wavy, and do not branch; and the bundles interlace in all directions: hence the flexibility and extensibility of this widely spread and important tissue. Its resiliency is due to the intermixture of numerous exceedingly fine fibres of *elastic* tissue.

Fig. 17.

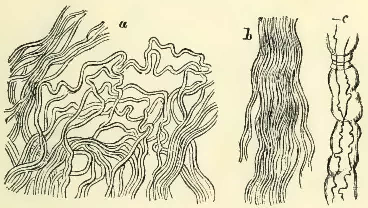


Fig. 17. *a*, interlacing bundles of colourless wavy filaments of the areolar connective tissue. *b*, parallel wavy filaments of the fibrous connective tissue. *c*, a single filament, swollen up after the addition of weak acetic acid, and showing certain fine dark fibres of elastic tissue coursing upon it. Magnified 400 diameters. (*a*, *b*, The Author; *c*, Kölliker.)

The *fibrous* form of the connective tissue consists of the same elements as the areolar form, viz. colourless filaments mixed with fine elastic fibres; but the white filaments, instead of being in open interlaced bundles, are arranged in close parallel ones, having a shining aspect, and marked with faint cross waves, fig. 17, *b*. The fibrous tissues, therefore, are not loose and extensible, but strong, unyielding and glistening. Straight intersecting bands, held firmly together in one plane by areolar tissue constitute the *fibrous membranes*, such as the

periosteum, the pericardium, the outer coat of the eyeball, the broader ligaments and tendons, and the strongest parts of the fascia investing the muscles of the limbs. Straight parallel bands closely held together, constitute flattened or rounded *fibrous cords*, such as certain ligaments, and the long tendons of many muscles.

The areolar and fibrous tissues are not very vascular; nor have they many nerves. They are almost insensible, except when inflamed. Tendons and ligaments suffer, however, from being overstretched.

Elastic tissue.—This tissue is so named because it is not merely extensible, but *retracts* after it has been stretched, like vulcanised india-rubber.

The very fine elastic fibres, which, as already mentioned, are mixed with the filaments of the areolar and fibrous tissues, are best shown by treating these latter with acetic acid, which causes the white filaments to swell up to a great size, whilst the elastic fibres remain singularly well defined, appearing as

Fig. 18.

Fig. 19.

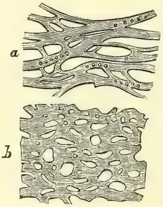


Fig. 18. Dark, clear branching, interlaced and curly fibres of the elastic tissue. Magnified 200 diameters. (The Author.)

Fig. 19. *a*, a layer of elastic tissue, in which the component fibres are flattened and joined together so frequently as to form a very close network. From the pulmonary artery of a horse. *b*, a still closer network of the same kind, forming a perforated or fenestrated elastic membrane. From the carotid artery of the horse. Magnified 180 diameters. (Kölliker.)

dark lines lying upon and even surrounding the white filament, fig. 17, *c*. When present as the chief constituent of any part, the elastic tissue has a yellowish colour; hence it is often called *yellow elastic tissue.* Its component fibres have remarkably dark outlines; they are never quite parallel to each other; they frequently branch and unite again; and when torn, their ends curl up, fig. 18. In this form the elastic tissue

exists in the two vocal cords of the larynx, and in certain peculiar ligaments of the spine. In the elastic coat of the arteries many of the fibres are flattened, and join together so frequently as to form a very close network, fig. 19, *a*, or even a *perforated membrane*, fig. 19, *b*. The elastic tissue is neither very vascular nor sensitive.

Adipose tissue or fat. — This tissue consists of numerous roundish or oval compressed vesicles, filled with an oily fluid and held in clusters by minute bloodvessels, and by the filaments of the areolar tissue in which they lie, fig. 20. The fatty matter within the vesicles, though fluid at the natural temperature of the body, becomes more solid as this gets cool, and sometimes even partly crystallises. In the state of emaciation, the fat vesicles become shrivelled and emptied of oil.

The fat acts as a filling or padding material in the body, between other parts; it also serves to smooth and round the

Fig. 20.

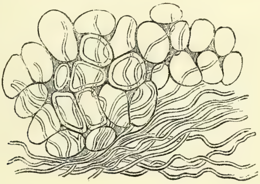


Fig. 20. Vesicles or cells of the adipose tissue or fat, supported by filaments of areolar connective tissue. The cells are supposed to be filled with an oily fluid. Magnified 100 diameters. (Sharpey.)

outline of the form; it acts as a non-conductor by which heat is retained in the body; and it is a store of nutriment always available for use. It is more abundant in children and in females, than in adults and males generally. The circumstances causing it to vary in quantity will be hereafter discussed. Fat is never found within the skull, where its alternate accumulation and disappearance might interfere with the functions of the brain; nor in the lungs, whose action it would impede; nor in the eyelids, whose movements it would hinder.

The *marrow* of bones is chiefly a fine adipose tissue. Fat generally is a very vascular texture; but it is supplied with very few nerves indeed.

Cartilage, fibro-cartilage, and *yellow fibro-cartilage.*—Pure

cartilage, or *articular* cartilage, such as covers the ends of the bones at the joints, is a firm, elastic opalescent substance, which consists of a homogeneous or faintly granular solid *matrix*, containing certain spaces in which are embedded the rounded or compressed bodies containing little nuclei, and called *cartilage cells* or *corpuscles*, fig. 21, *a*. Near the free surface of a cartilage these corpuscles are flattened out, but deeper they are arranged vertically, so that the cartilage splits more easily in that direction. In the cartilages of the larynx and windpipe, in the gristly part of the nose, and in the cartilaginous portions of the ribs, which are fixed to the breast-bone, the matrix is indistinctly striated. The cartilages of the ribs and larynx become bony in old age.

Fig. 21.

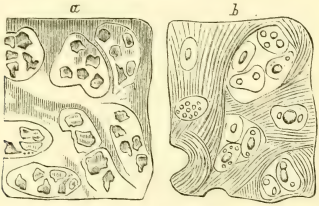


Fig. 21, *a*, a small piece of articular cartilage, from a joint, showing its solid matrix and the cartilage cells, with their little contained nuclei, embedded in it. *b*, portion of a white fibro-cartilage, consisting of nucleated cartilage cells, embedded in a somewhat fibrous matrix. Magnified 260 diameters. (*a*, Sharpey, *b*, Kölliker.)

Fibro-cartilage may be regarded as a mixture of cartilage and fibrous tissue, or as cartilage with a distinctly fibrous matrix, containing cartilage-corpuscles and nuclei, fig. 21, *b*. It is found in certain joints, as will be hereafter explained.

In *yellow fibro-cartilage*, the fibrous part is soft and resembles *elastic tissue*. Examples of it are found in the ear, eyelids, and valve-like epiglottis.

Articular cartilage is absolutely without bloodvessels, *i. e.* is non-vascular. The other kinds are all slightly vascular; and they also have a fibrous membrane investing them called the *perichondrium*, which is vascular. No nerves have been seen in them.

Osseous tissue or bone.—The outer so-called *compact* tissue of bone is not quite solid, but is traversed by minute tubes

called the *canals of Havers*, which form a longitudinal network in the *bone-substance*, and open by minute pores on the surface. The finest canals are near the surface of the bone: further in, they get larger and at length open into obvious channels which becoming still wider, form at length the *cancelli* of the spongy tissue, which finally merge, at least in the long bones, into the central cavity for the marrow or *medullary cavity*, fig. 22, *a*. When more highly magnified, *b*, and fig. 23, the bony substance surrounding these canals and cancelli, is seen to be arranged in concentric *laminæ* firmly united together, and having lying between them very minute cavities called the *lacunæ of bone* or *bone corpuscles*, from which numbers of exceedingly fine tubuli called *canaliculi*, pass into the solid substance of the laminæ,

Fig. 22.

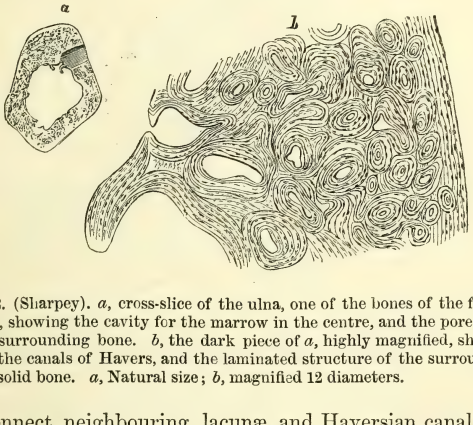


Fig. 22. (Sharpey). *a*, cross-slice of the ulna, one of the bones of the fore-arm, showing the cavity for the marrow in the centre, and the pores in the surrounding bone. *b*, the dark piece of *a*, highly magnified, showing the canals of Havers, and the laminated structure of the surrounding solid bone. *a*, Natural size; *b*, magnified 12 diameters.

and connect neighbouring lacunæ and Haversian canals. In the living state, the Haversian canals are occupied by small often capillary bloodvessels, which enter the bone from the periosteum, and communicate also with the bloodvessels of the marrow. Bone is therefore a very vascular tissue: most of its vessels reach it from the periosteum; but in the long bones, there is usually an artery for the medulla which enters the bone by a distinct orifice. A nerve enters at the same opening; but bone is not sensitive unless inflamed.

Dry bone consists of two-thirds of earthy matter and one-

third of animal matter, the two being everywhere intimately blended; for the former may be removed by acids, and the latter by burning, without destroying the shape of the bone. In bone softened by acid, a fibrous structure can be shown in the laminæ. Healthy bone is a very strong material: it is somewhat elastic; and the hollows in its substance, besides facilitating its nutrition, make it mechanically better fitted for its purposes, by spreading out a given weight of substance into more space, and making it proportionally more resistent.

Fig. 23.

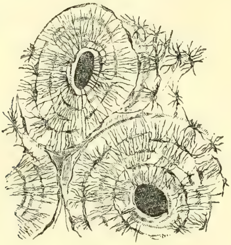


Fig. 23. (Sharpey.) A very fine section of bone, showing two of the canals of Havers, with the surrounding bony laminæ, between which are the little bodies called the corpuscles or lacunæ of bone, with fine lines radiating from them, called the canaliculi of bone. This section is supposed to be examined on a black ground, so that the hollow parts are dark, and the solid parts white. Magnified 90 diameters.

Muscular tissue.—There are two kinds of muscular tissue in the body, one consisting of *plain* or *unstriped muscular fibres*, and the other of *striped* or *striated muscular fibres*. The former kind is found in the walls of the alimentary canal, in the sides of the air tubes and ducts of glands, in the skin, and in the coats of the bloodvessels and larger absorbent vessels. The latter kind forms the substance of the muscles of the body; but the substance of the heart also consists of an imperfectly characterized striated muscular tissue.

The *plain* or *unstriped* muscular fibres are soft, pale, smooth, and roundish or slightly flattened, fig. 24, *a*. Their substance is indistinctly granular, as if composed of fine particles, called *sarcous elements* (from *sarx*, flesh), in or upon which are *elongated* bodies, or *nuclei*. When treated with

diluted acetic acid, the substance of the fibre becomes transparent and the nuclei very distinct (see the fibre to the right). Nitric and chromic acids break them up into *fusiform bodies* called *fibre-cells*, as at *b*, each including one of the nuclei, but being without a recognisable envelope or limiting membrane. In certain parts, as in the spleen of animals, in medium-sized bloodvessels, and in the skin, single fusiform fibre-cells exist; but, in most places, these are joined in an overlapping manner, to form the so-called plain muscular fibres. In the coats of the alimentary canal and elsewhere, these fibres form interlacing bands arranged in broad layers or tunics. Their extremities are never attached to bone, but pass into bundles of fibrous connective tissue, and, in the gullet, have been seen

Fig. 24.

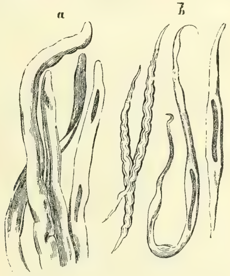


Fig. 24. *a* (The Author), portions of four plain or unstriped muscular fibres from the bladder; that on the right is rendered transparent, and its contained nuclei more evident, by being acted on by acetic acid. Magnified 170 diameters. *b* (Kölliker), two plain muscular fibre-cells from the pig's gullet, treated with nitric acid; one long one from the human intestine, and one from the coats of the dog's spleen, not treated with nitric acid. Magnified 200 diameters.

to present microscopic tendinous intersections. In the windpipe, they terminate in bundles of elastic tissue; in the skin, often on the sides of the hair-follicles.

The *striped* or *striated muscular fibres*, fig. 25, are far more elaborately organised, presenting a much more definite and regular structure. They are soft, compressed or prismatic in shape, and marked with beautifully-regular cross lines or *striæ*. Each fibre is enclosed in a delicate glassy-looking structureless tube called the *sarcolemma*, as shown in the ruptured fibre, *b*;

upon, or within, the sarcolemma, numerous nuclei containing one or more nucleoli are seen on the application of acetic acid. The soft substance of the fibre, transparent and of a yellowish

Fig. 25.

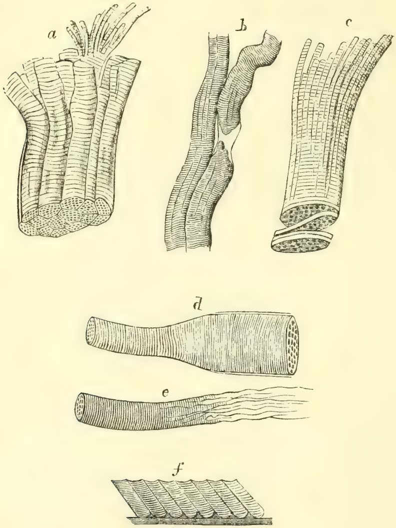


Fig. 25. *a* (The Author), a small muscular fasciculus, composed of parallel prismatic muscular fibres, marked with cross lines or striæ; one of the fibres is split into the finer threads called fibrillæ or filaments. *b* (Kölliker), two muscular fibres, one broken inside the tubular sheath called the sarcolemma. *c* (after Bowman), a single fibre more magnified, showing the longitudinal and transverse striæ; also the lateral adjustment of the sarcous elements of its component fibrillæ, which explains the cross striæ; and the occasional cross splitting of a fibre between rows of sarcous elements into discs. *d* (Bowman), a muscular fibre partly in a state of rest, and partly (to the left) in a condition of contraction. *e* (Kölliker), mode in which a muscular fibre changes, in becoming attached to, or continuous with, the fibrous connective tissue of tendons or periosteum. *f* (Kölliker), oblique insertion of muscular fibres into tendon. *a*, *b*, *d*, and *e* are magnified about 150 diameters, *c* 300, and *f* 70 diameters.

hue, consists of numerous fine threads called *fibrillæ* or *filaments*, *a* and *c*, which are themselves composed of rows of coherent quadrangular particles called *sarcous elements*. The existence

of the fibrillæ gives rise to faint longitudinal lines in the fibres; whilst the equal size, the uniform arrangement, and the accurate adaptation of the sarcous elements, which act peculiarly on transmitted light, produce the more evident transverse striæ. Sometimes, even, as shown in *c*, a fibre splits into transverse discs opposite the intervals between corresponding rows of sarcous elements. When a single fibrilla is very highly magnified, its component row of oblong sarcous elements presents alternate *dark* doubly-refracting, and *light* singly-refracting quadrangular portions, in the latter of which a delicate cross line is sometimes seen. The dark portions have been described as crystalline, and as being composed of minute doubly-refracting particles, named *disdiaclasts.*

In the formation of *muscles*, the fibres are collected into

Fig. 26.

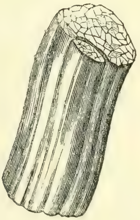


Fig. 26. (The Author.) A short piece of a compound muscular fasciculus, showing, on its cut end, its component little bundles, or ultimate fasciculi. Slightly magnified.

minute fasciculi or bundles, *a*, named the smallest fasciculi, which, again, are gathered parallelly into larger bundles, and these into still larger ones, as shown in fig. 26. Each muscle is invested by a sheath of areolar tissue, named the *perimysium*, from which fine partitions of the same tissue, supporting the bloodvessels and nerves, pass inwards between the fasciculi and fibres. Most of the muscles are fixed to the bones, either directly or indirectly, by means of tendons; but, even in the former case, the individual muscular fibres are attached to the bone indirectly through the fibrous tissue of the periosteum. Some muscles, however, are fixed to soft parts, as to the tongue, lips, and eyeballs; either directly, as in the two former cases; or indirectly, by tendons, as in the last. In all instances, however, each fibre, as it ends, breaks up and merges

into a bundle of fibrous connective tissue, either as shown in fig. 25, *e*, or by first coming down obliquely on a tendon as in *f*. Usually the individual muscular fibres run along a fasciculus without branching; but in the tongue, lips, and face, they subdivide before they are lost in the submucous or subcutaneous tissue.

In the heart, the muscular fibres are striated; but the tubular sarcolemma is indistinct or absent. Moreover, the fibres themselves subdivide and unite again, so as to form a network; the bundles of fibres also frequently interlace; and, in some animals at least, fusiform nucleated fibre-cells have been seen amongst them. The heart substance, therefore, shares the characters of both the striped and unstriped muscular tissue. Moreover, these two forms of muscular tissue have another transitional or connecting link between them; for sometimes the unstriped fibres have their granules or sarcous elements arranged in rows as disdiaclasts, thus imperfectly but decidedly approaching the character of the striped fibre.

The striped or ordinary muscles are exceedingly well supplied with blood,—their minute or capillary vessels running between the individual fibres, and forming elongated meshes, as shown in fig. 35, *a*. Lymphatic vessels are absent, or very few. The nerves of the striated muscles are likewise very abundant; they come from the cerebro-spinal system: their mode of termination will be presently adverted to. (See fig. 30.) The vessels and nerves of the non-striated muscles are not quite so numerous; their nerves are derived chiefly from the sympathetic system.

Nervous tissue.—The brain, spinal cord, and nerves consist essentially of the grey and white nervous substances which, besides connective tissue and bloodvessels, in which latter the grey substance is very rich, contain three distinct microscopic elements, viz. *nerve-cells* or *ganglionic corpuscles*, *grey* or *gelatinous fibres*, and *white* or *tubular nerve-fibres*. In some situations, growing cells, free nuclei, and granules are found, as, for example, in the cerebellum.

The *ganglionic corpuscles*, fig. 27, are nucleated cells, that is, vesicular bodies containing, besides a pulpy matter, an eccentric roundish body or nucleus, enclosing one or more nucleoli, surrounded by coloured granules. Some of these nerve-cells are rounded, others oval, some pyriform or pear-shaped, others caudate, and some stellate or provided with branched offsets, completely continuous with the cell-wall and the contents of

the cell itself. They are found in the grey substance of the cerebrum and cerebellum, as *c*, *d*, *e*; in the spinal cord, *b*; in the knots or ganglia of the sympathetic nerve, *a*; and at the terminal expansions of the nerves of sight and hearing; also

Fig. 27.

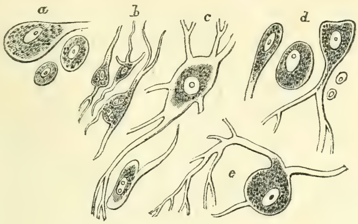


Fig. 27. (Kölliker and Hannover.) Coloured cells, containing nuclei, called nerve-cells, ganglionic cells, or ganglionic corpuscles. *a*, cells of simple form from a sympathetic ganglion. *b*, branched cells, or stellate cells, from the grey substance of the spinal cord. *c*, branched cells of larger size from the medulla oblongata. *d*, simple and branched cells from the superficial part or convolutions of the brain. *e*, a large cell from the grey substance of the cerebellum. Magnified about 100 diameters.

on the nerve-terminations in glands and perhaps elsewhere. They vary in size in different situations. The nerve-fibres usually pass amongst them, fig. 29, *d*; and, whilst some of the branched offsets of the cells serve undoubtedly to connect different cells together, others, it is stated, are continuous with the tubes of the white or tubular nerve-fibres. It is important to note, however, that this latter statement, though probably correct, is more a matter of inference than of direct observation, in so far at least as concerns the brain and spinal cord of man and the higher animals. In the ganglia, however, both in man and animals, this connection has been distinctly seen. According to the number of their offsets and connections, nerve-cells have been named *unipolar*, *bipolar*, or *multipolar*. Cells apparently destitute of them are described as *apolar*. The existence of such free cells has however been denied; and the so-called unipolar cells are said to have another filament passing from them, often twisted round the one which is more evident (Beale).

The *grey* or *gelatinous fibres* (Remak's fibres) are very simple

in structure, being soft granular flattish fibres, having no distinct tubular and medullary investment, and containing many dark nuclei, fig. 29, *d*. These fibres are most abundant in the sympathetic nerve and its branches, but a few extend into the spinal and cranial nerves. Some of these are regarded as connective tissue fibres, and not as nerve-fibres at all.

The *white* or *tubular nerve-fibres*, fig. 28, *b*, are microscopic tubuli, which when freshly examined in a perfect state appear to be homogeneous, but which, even on cooling, soon acquire

Fig. 28.

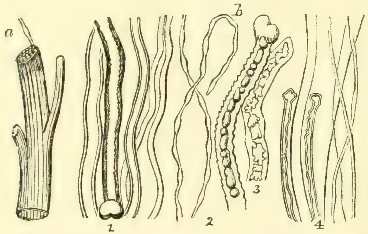


Fig. 28. *a* (The Author), portion of a spinal nerve giving off two branches, shown to be composed of a number of parallel cords called funiculi (of which one is seen projecting), enclosed in a sheath. Magnified slightly. *b* (Kölliker), white tubular nerve-fibres from different parts of the nervous system, in different states. Magnified 260 diameters. 1, five fibres of different sizes from nerves, three having the double outline. 2, two fibres which have become varicose after removal. 3, two fibres the fatty contents of which have become altered by the action of water. 4, fibres from the brain: one large one, showing the outer tube, the central axis or cylinder projecting at the upper end, and the intermediate white or medullary substance. The four last fibres are remarkable for their fineness.

a characteristic dark, smooth, double outline or contour, 1, and which may quickly, from pressure or other causes, become varicose or beaded, 2. Each tube consists of an outer *structureless membrane*, enclosing a layer of transparent fluid fat, or *medullary* matter, which, after death, 3, is apt to lose its clear homogeneous appearance, and become congealed into drops or masses, or to project from the broken or cut ends of the tubes. Within this medullary matter, or *white substance* of Schwann, as shown in fig. 28, 4, is a firmer part or core, called the *central band-axis*, or *axis cylinder*, which is not fatty but

albuminoid. This central band is very important, as it is sometimes the only part of a nerve-fibre left within the tubular structureless sheath, constituting thus the so-called pale *non-medullated* nerve-fibre. This axis is also the part which is said to be continued into the delicate offsets of the branched nerve-cells, those processes being identical in structure with the non-medullated nerve-fibres. As the medullary substance in the tubular fibres forms a covering around the central band, it is spoken of as the *medullary sheath.* These medullated, tubular nerve-fibres compose the white parts of the brain and spinal cord, and the chief substance of the various nerves; but they also pass into and mix with the grey substance of the brain, cord, and ganglia. They vary much in size (see fig. 28), being finest of all, 4, in the superficial layers of the brain, fine in the nerves of special sense, and in the ganglia, larger in the fore part of the spinal cord, and largest in the motor nerves.

Fig. 29.

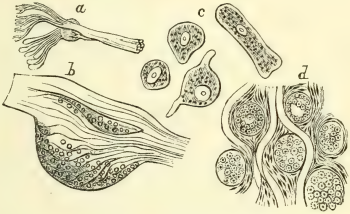


Fig. 29. (*a*, *b*, Kölliker; *c*, *d*, Valentin.) *a*, origin of a spinal nerve from the spinal cord, by two bundles of funiculi, or two roots, which join to form the trunk of the nerve. On one of the roots,—the posterior one in the body,—is a small knot called a ganglion; the other, or anterior root, is seen to pass over the ganglion without entering it. *b*, section plan of a ganglion, showing the fibres of the posterior root passing amongst the ganglionic corpuscles, and the fibres of the anterior root passing over them. *c*, four separate ganglionic cells from a spinal ganglion, of different shapes. *d*, minute portion of a ganglion, showing six corpuscles, three white tubular nerve-fibres, and a number of the grey nerve-fibres or connective tissue-fibres with little dark nuclei. *a*, natural size; *b*, magnified slightly; *c*, *d*, about 100 diameters.

Within the grey substance of the nervous centres, the white nerve-fibres either commence from the processes of certain of the nerve-cells, or appear as loops running between those cells. Even in the latter case they may have their origin in cells not

immediately under observation. Indeed, the view has lately been advanced, that *all* nerve-fibres originate in nerve-cells; and it has further been argued that, most probably, each cell is the centre of one or more complete circuits, a fibre or fibres passing from and returning to it again. (Beale.) As they pass out from the base of the brain, or from the sides of the spinal cord, the nerve-fibres form bundles of little cords, named *funiculi*, fig. 29, *a*, which are soon gathered into a cluster or *nerve-root*. In the spinal nerves there are *two roots*,—one posterior, the fibres of which go through a knot or *ganglion* of grey substance, *a*, *b*, and one anterior, the fibres of which go past the ganglion; both sets join beyond the ganglion to form a single *nerve-trunk*. In the nerves, and their branches, fig. 28, *a*, the tender funiculi are supported in bundles by the *neurilemma*, a soft sheath, having partitions in it, composed of a form of connective tissue, and continuous with the membranes of the brain or spinal cord. The bundles and even the funiculi often split and interlace, to form *nervous plexuses*, but the ultimate nerve-fibres, it is believed, do not subdivide, at least in their course, and remain of uniform thickness.

The nerves appear sometimes to end in loops, sometimes in *meshes*, but more frequently by *free extremities* with or without previous *subdivision*, in the various tissues to which

Fig. 30.

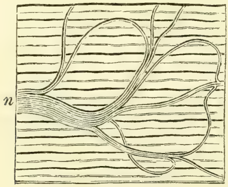


Fig. 30. (Burdach.) Plan of a thin portion of muscle, showing its parallel fibres slightly waved or ziz-zag; and a small nerve, *n*, composed of a bundle of white tubular nerve-fibres, which pass over and amongst the muscular fibres and form returning loops. Magnified 30 diameters.

they go. In the muscles, as shown in fig. 30, white tubular *motor* nerve-fibres, once considered terminal, form rather wide loops, which cross amongst the muscular fibres; but, according to recent observations on the muscles of the lower animals, these loops are by no means the real terminations

of the nerves. All agree that the dark-bordered or medullated fibres of the motor nerves give off very fine non-medullated branches, which either end in fine points, or else form a delicate network upon the muscular fibres; and these fibres are marked by numerous attached nuclei; and most authorities agree, that they do not penetrate within the sarcolemma. Other appearances have also been described, such as *terminal nerve-buds*, or blunt *knob-like* endings of the dark-bordered fibres, and more recently the so-called *terminal plates* of those fibres, from which non-medullated fibres arise. These terminal plates, one to each fibre, are said to be found only near the middle, not at the ends of a muscle; they are compared to certain parts of the electric organs of fishes; they are described as consisting of areolar tissue, as partially embracing a fibre, and as being placed at the point whence the non-medullated fibres are given off from the dark-bordered ones. The *sensory* nerve-fibres of muscles end also in pale non-medullated branches; but they are finer, and are distributed on the surfaces of the muscle, or of its principal bundles. In the papillæ of the tongue and skin the sensory nerve-fibres sometimes really form elongated loops; but here, as in other situations, they may lose their medullary substance and double contour, and perhaps even their tubular envelope, so as to be reduced to the axis or central band only, and then end amidst the tissues to which they are distributed,—either abruptly by swollen extremities, or after previously becoming finer and finer, or even after subdividing into fine twigs. The reticular mode of termination of the nerve-fibres has been observed in the retina of the eyeball, and in the submucous tissue of the intestines. Special modes of termination in the organs of sense, and, in certain bodies, the tactile and Pacinian corpuscles, in the skin, will be described hereafter.

The bloodvessels.—The three kinds of bloodvessels, *arteries*, *veins*, and *capillaries*, differ very much in their structure.

The *arteries*, the strong yellowish or white cylindrical branching tubes which proceed from the heart to all parts of the body, have thick elastic walls; so that they remain open when they are cut across. These walls consist of three coats, fig. 31, *a*, viz. of an external coat, composed of areolar and elastic tissue; of a middle or muscular coat, the thickest, composed of unstriped muscular fibres arranged circularly around the vessel, mixed with a very few elastic fibres; and of a thin smooth internal coat, consisting chiefly of a fenestrated or striated elastic

membrane, fig. 19, lined by the vestiges of a delicate epithelium, fig. 43, *c*. The inner coat is brittle, and the middle one tender; the outer one is very tough; so that a string tied tightly round an artery cuts through the middle and inner coats but not the outer. The smaller arteries have relatively more muscular tissue, and the larger ones relatively more elastic tissue, in their walls. The outer and perhaps the middle coats of the arteries are themselves vascular, being supplied with nutrient bloodvessels, called the *vasa vasorum*. The arteries are supplied with nerves derived chiefly from the sympathetic system. In the limbs, all but the very finest arteries have a loose sheath of areolar tissue, in which they can be moved.

The *veins*, which, proceeding from all parts of the body, end in the heart, are more yielding tubes and have thinner walls

Fig. 31.

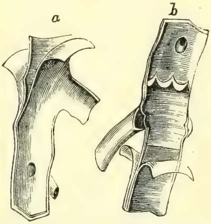


Fig. 31. (The Author) *a*, a portion of a medium-sized artery laid open, showing its three coats, viz. the external areolar coat, the middle muscular coat, and the internal elastic and epithelial coat. *b*, a piece of a medium-sized vein laid open, exhibiting its three coats. Besides this, it shows the valves in the interior of the vein.

than the arteries, so that they collapse when cut across. Their coats are also three in number, fig. 31, *b*, and similar in general structure to those of the arteries; but the middle coat contains fewer unstriped muscular fibres, and the internal coat has no fenestrated layer, except in the veins of the pia mater of the brain, though it has fine elastic fibres and vestiges of a delicate epithelium, fig. 43, *b*. In the largest veins, there are muscular fibres in the outer coat; and all the coats of the veins in the limbs, especially in the lower limbs, are thicker than elsewhere. Upon the great veins as they are entering the auricles of the

eart, even a few striated muscular fibres may be found. he veins have their vasa vasorum, and a few nerves. Within iany of the veins, at certain intervals, and also at the mouths of ieir branches, fig. 31, are found little projecting folds or flaps, alled *valves*, formed by the internal coat, strengthened by a ew fibrous bands. These are either single, double, or even iree in number; and are always so attached that their free dge is towards the heart. They are most numerous in the eins of the limbs, especially of the lower limbs. Valves are ot found in the smallest veins, nor in the largest, as the venæ avæ; nor are they found in the pulmonary veins or hepatic eins, which return the blood from the lungs and liver. 'hey are also absent in the cranial, spinal, renal, portal, and few other veins.

The *capillaries* are the intermediate vessels which connect

Fig. 32.

Fig. 32. (Allen Thomsón.) Outline of the under surface of a frog's hind foot, to show the general branching of its small arteries and veins, in the web between the toes.

he finest arteries with the finest veins. They are quite peculiar n structure. The arteries, branching out as they run from he heart into every vascular tissue of the body, become at ast very small, and have very thin coats. Ultimately they end in a fine *network* of vessels called the *capillaries* (*capillus*, a hair), from which the smallest veins commence. These small veins at first have very thin coats, but, continually joining

together to form larger and larger veins, at length run in a few main trunks to reach the heart again. The heart, arteries, capillaries, and veins form therefore a closed system of chambers and tubes, in which the blood is contained; and, as we shall see hereafter, whilst the heart and all the bloodvessels are concerned in conveying the blood through the body, it is the delicate capillaries only which permit nutritive material to pass from the blood through their coats into the tissues.

The ramified course of the bloodvessels generally is well seen in the web of a living frog's foot, fig. 32; the capillary network itself in the same part becomes visible with the aid of a low magnifying power, as in fig. 33; and under a much higher power, fig. 34, the tubular character and distinct pa-

Fig. 33.

Fig. 34.

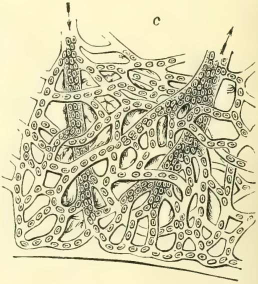


Fig. 33. (After Wagner.) A piece of the frog's web, with a portion of a toe, slightly enlarged, showing the fine capillary network connecting the terminations of the arteries with the commencement of the veins.

Fig. 34. (Allen Thomson.) Minute piece of the margin of the frog's web, showing the ultimate bloodvessels or capillaries, connecting the end of a small artery with the beginning of a minute vein. The oval blood-corpuscles are seen in these vessels, and the arrows entering and passing out of the artery and vein indicate the course of the blood-current. Magnified about 30 diameters.

rietes of the capillary vessels, the mode in which they connect the fine arteries and veins together, and their contained blood, are distinctly perceived.

In the vascular tissues of the human body also, the capillaries usually form a network, which may consist either of

elongated meshes, as in muscle, fig. 35, *a*, in tendons, and in nerves; of a polygonal network, as in smooth mucous membranes, *b*; of long loops, as in the skin, fig. 36, *a*; or of close meshes, as in the small intestine, *b*; or of still closer meshes, as on the ducts of glands, fig. 37. The finest meshes of capillaries are found in the lungs. The capillary vessels vary in size in the different vascular tissues: they are very large

Fig. 35.

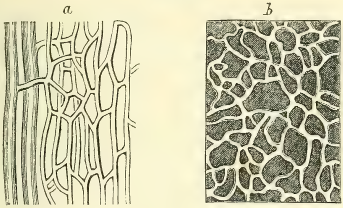


Fig. 35. *a* (Kölliker), capillaries of muscle, forming long meshes. *b* (The Author), capillaries of a smooth mucous membrane, forming large polygonal meshes. Moderately magnified.

Fig. 36.

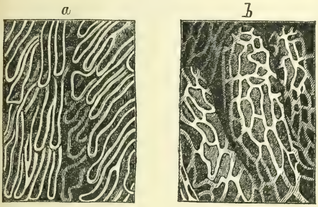


Fig. 37.

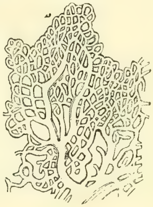


Fig. 36. *a* (Berres), capillaries of the papillæ of the skin of the tip of the finger, forming single loops. *b* (Berres), capillaries of the villi or little projections of the mucous membrane of the small intestine, forming small meshes. Moderately magnified.

Fig. 37. (Quekett.) Capillaries of the terminal extremity of a duct of the parotid gland, forming very close meshes. Moderately magnified.

in bones, and smallest in the lungs and in the brain. The smallest capillaries, however, admit the little bodies which are found in the blood, called the red blood-corpuscles. Tissues which are destitute of capillary vessels, such as the cartilages of the joints, certain transparent parts of the eyeball, including the clear coat or cornea, the substance of the teeth,

the epithelial tissues, and the cuticle or outer skin and it appendages, the nails and hairs, are called *non-vascular*.

When a capillary vessel is very highly magnified, as in fig 38, its walls are seen to be exceedingly thin and delicate, an to be composed of homogeneous membrane in which many nuclei are set: on approaching the smallest arteries and veins the capillaries gradually acquire extra coats and so pass int those vessels. The walls of all these small vessels are of cours without vasa vasorum.

The blood.—The blood, the fluid contents of the blood-vessels, is of a bright florid colour in the arteries, and of a dark purple tint in the veins. It is, apparently, a red homogeneous solution, but it really consists of a clear, limpid, almost colourless liquid, named the *liquor sanguinis*, the liquor or *plasma* of the blood, and of certain floating particles called *blood-corpuscles*. These latter are of two kinds, the *red* or

Fig. 38.

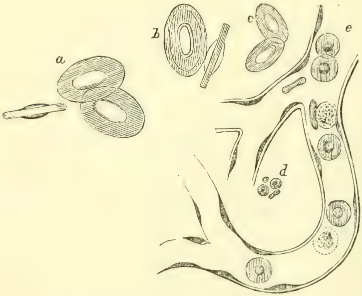


Fig. 38. *a* (Wagner and Kölliker), three red blood-corpuscles from the frog, one turned on its edge: they show the pale central nucleus and the outer coloured part. *b*, two red blood-corpuscles of the monk-fish, one seen edgeways. *c*, two red blood-corpuscles of the common fowl. *d*, three minute red blood-corpuscles of the goat. *e*, human capillary vessel from the brain, showing its transparent walls and the nuclei embedded in them; and also seven red and two white blood-corpuscles within the capillary tube. Magnified 400 diameters, all on the same scale, to show the relative sizes of the different blood-corpuscles.

coloured corpuscles, and the *white corpuscles*. Blood also contains albuminous granules and fat particles, besides other occasional microscopic elements, such as clustered blood-corpuscles, pigment granules, and caudate cells, the chief of which will be described hereafter with the spleen.

The *red corpuscles*, which are present in enormous numbers, and on which the colour of the blood entirely depends, are minute circular discs, fig. 38, *e*, depressed a little on each side. Seen edgeways they appear rounded at the margins, and they are so soft and flexible as to bend easily around any obstacle (see fig. 38, *e*). They are singly of a pale amber colour; but, when collected in numbers, they produce a reddish hue. In blood, drawn from the vessels, the red corpuscles exhibit a curious tendency to run together into little rolls like coins: they are heavier than the plasma of the blood. Each corpuscle is usually regarded as a distinct vesicle, or so-called *elementary cell*, consisting of a very delicate elastic envelope or cell-wall, and a contained soft coloured substance: the centre is clearer and paler, and looks like a central body or so-called nucleus, but in the perfect corpuscle there is no distinct nucleus.

Coloured blood-corpuscles in animals.—In the mammiferous animals generally, the red corpuscles are also round, disc-like, non-nucleated bodies. In the camel tribe they are elliptical; in the deer and goat tribes, *d*, they are circular though small; they vary in size in different mammalia; and, so far as is known, are largest in the elephant, and smallest in the musk deer. In birds, *c*, reptiles, amphibia (frogs and newts), *a*, and most fishes, *b*, the blood discs are oval, and present a central elevation on each surface. They are larger in birds than in mammalia, still larger in fishes generally, and of yet greater size in the amphibia, being largest of all in the proteus. Their dimensions in a few animals will be given hereafter. In birds, reptiles, amphibia, and fishes, the coloured blood-corpuscles are what are termed *nucleated cells*, possessing, besides an external envelope, a distinct projecting central body or *nucleus*, and an intermediate coloured substance. In the frog, the nucleus occupies often one-third of the length of the corpuscle; as it is not visible when the corpuscles are still in the living vessels, it has been supposed by some to be the result of a subsequent process of aggregation within the corpuscle.

Many microscopic observers doubt or deny the existence of a cell-coat or envelope, not only in the human and general mammalian blood-corpuscle, but even in the larger corpuscles of the frog. They describe these bodies as little soft, elastic, homogeneous masses, having the outer layer a little more condensed than the interior, excepting the so-called nucleus when it is present. By some, the non-nucleated mammalian red corpuscles are regarded as free nuclei, specially modified (Gulliver, W. Jones); but it is said that they even possess a double cell-wall (Roberts); so that they might be regarded as small cells, completely filled by a vesicular nucleus.

The *white corpuscles* of the blood, much fewer in number

than the red, the proportions between them averaging from 2 to 3 in 1000, are colourless, transparent, and spherical *nucleated cells*, having no distinct envelope, but a finely granulated surface, granular contents, and, as shown by the action of acetic acid, a simple or compound nucleus in their interior, fig. 38, *a*. They are not so heavy as the red corpuscles, and refract light more strongly. They do not run together into rolls like coins, nor do they change their form by bending within the vessels. Lastly, they are more uniform in size and shape in different animals than the red corpuscles, being nearly of the same size and character throughout, however widely the coloured ones differ in these respects. They have a general resemblance to the corpuscles of the lymph, to be immediately described; but these latter are said, as we shall see, to be nuclei and not nucleated cells. After a meal, true lymph cells also may be sometimes found in the blood.

White corpuscles in animals.—In the frog, the proportion of the white corpuscles to the red is 1 to 16 in winter, and 1 to 6 in summer. The singular little fish named the lancelet, or amphioxus, is the only one of the so-called vertebrate animals (of which it is the simplest yet discovered), in which the blood has no red corpuscles, but only colourless ones. The corpuscles found in the blood of still lower animals, such as cuttle-fish, insects, crabs and others, are also generally free from colour, and are usually discoid in shape.

When blood is diluted with water, the red corpuscles swell, become indistinct, and finally burst: when any agent, such as salt or syrup, which increases the density of the blood, is added to it, these same corpuscles shrink and assume various irregular forms. Sometimes, whilst being examined under the microscope, without any known cause, they become indented or jagged at the edges, or otherwise altered in shape. In certain cases, this may be owing either to pressure, evaporation, special aggregation, or decomposition. The white corpuscles, on the other hand, have been seen to thrust out little buds, and so even become stellate, whilst they may yet be regarded as living. It has been said that oxygen gas distends the red corpuscles, whilst carbonic acid gas shrinks them up; but this is not well established. Acetic and other acids swell and ultimately dissolve them. The appearance of an envelope, and the pale nucleus or nuclei of the white corpuscles, are best seen after the action of very dilute acetic acid, when the corpuscle presents a smooth outline, and the nucleus often a reddish hue: very strong acetic acid causes the nucleus to divide into two or three separate parts.

When blood is drawn from its vessels, it sets, *coagulates*, or *clots*, separating into a red jelly-like mass, which is called the *clot*, and a thin fluid which oozes from the clot, named the *serum* of the *blood.* In the act of clotting or coagulation, the liquor sanguinis or fluid part of the living blood is said to separate into two parts, viz. into a small quantity of a solid substance called *fibrin*, which solidifies into minute fibrils, and a residual liquid part, of a pale yellowish hue, which is named the *serum* of the blood. Whilst thus separating and solidifying, the fibrin entangles in its meshes the red and white corpuscles of the blood, and so forms the *coagulum*, *crassamentum*, or *clot*, from which the serum runs out. The fibrin may be separately obtained by whipping freshly drawn blood for several minutes with a bunch of sticks, to which it then adheres in a stringy mass. The relative constitution of fluid and clotted blood may be thus expressed:—

Fluid Blood.		*Clotted Blood.*
Liquor sanguinis	Serum	Serum
	Fibrin	
Corpuscles.	Corpuscles.	Clot.

The nature and cause of the coagulation of the blood will be considered in the chapter on the Circulation.

The absorbent vessels, or lymphatics and lacteals.—These vessels form a closed set of tubes distributed nearly everywhere throughout the body, and ending by the thoracic duct, and certain smaller trunks, in the great veins at the root of the neck (fig. 100).

The finest lymphatics are supposed to commence on the surfaces of membranes, by a close network of delicate vessels, which are much larger than the capillaries, and have no direct or open communication with them. Those of the skin are represented, somewhat magnified, in fig. 39. The mode of origin of the lymphatics arising in the interior of the muscles and of the organs generally, is not well known. In the tadpole's tail they have been seen as ramified vessels, shooting out many fine pointed processes. In the kidney of the mammalia, it is alleged that they commence in the lacunæ or spaces in the areolar connective tissue. The lymphatic vessels which course along the limbs or organs of the body, as shown in fig. 100 are little delicate, transparent, varicose tubes, which escape observation unless they are distended with lymph or chyle, or are in some way artificially injected. Their appearance when

distended is represented in fig. 40, *a*; and when opened, as at *b*, a pair of valves is seen opposite each constriction. The edges of these valves are usually turned obliquely towards the terminations of the lymphatics in the veins; that is, in the ordinary direction of the fluid which flows along the absorbents; but they are said to be sometimes disposed transversely. The walls of the commencing lymphatics are homogeneous; but the large vessels, including the thoracic duct, have coats similar to those of the veins, composed of areolar, elastic, and even unstriped muscular tissue, and are lined by a fine epithelium.

Fig. 39.

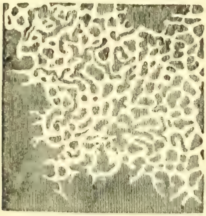


Fig. 40.

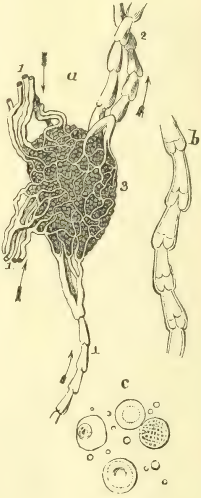


Fig. 39. (Breschet.) Network of the superficial lymphatics of the skin, injected with mercury. Moderately enlarged.

Fig. 40. (Mascagni), *a*, plan of a lymphatic gland, 3, with its component cells filled with mercury, and having three sets of afferent vessels, 1, 1, 1, leading into it, and one set of efferent vessels, 2, passing out from it. The arrows indicate the course of the lymph in these vessels. The varicose or jointed appearance of the vessels is here shown. *b*, a single lymphatic vessel somewhat enlarged, and cut through, to show the little double valves in its interior. *c*, lymph corpuscles, one granular, and three treated with dilute acetic acid showing the envelope and the pale nucleus; also some finer granules and oil particles free. Magnified 400 diameters.

The *lymphatic* or *absorbent glands*, or *lymphatic ganglions*, are the firm, oval or roundish bodies placed at certain points in the course of the lymphatics and lacteals (see fig. 100.) They are composed, as shown in fig. 40, *a*, 3, of a number of imperfect cells or alveolar spaces filled with lymph or

chyle, into which certain lymphatic vessels, called *afferent vessels*, *a*, 1, 1, enter, and from which other lymphatics called *efferent* vessels, 2, pass out, the whole being held together by intermediate areolar tissue, and enclosed in a proper areolar coat or investing membrane, which is perforated by the larger bloodvessels and absorbents. On a section, a lymphatic gland is seen to be made up, first, of an outer *cortical* part, composed of rounded or polygonal alveolar spaces or cells, from $\frac{1}{3}$rd to $\frac{1}{8}$th of a line wide, and crossed by numerous trabeculæ, of fine *retiform* or *reticular connective tissue*; and secondly of a *medullary* part within, consisting of a fine plexus of lymphatic vessels. The afferent lymphatics enter the cortical substance at several points, and pass into its alveolar spaces, from which other finer lymphatics proceed, and form the plexus in the medullary or central part. From this plexus, the efferent lymphatics arise, and emerge from the gland frequently at a sort of fissure, sometimes named the *hilus*.

The *fluid* found in the lymphatic vessels is clear and colourless, but occasionally has a pale yellow hue; it is called *lymph*. It consists of a fluid part, or *liquor lymphæ*, which contains *nuclei*, minute *granules*, and, but seldom, a few *oily globules*. In the cells or alveolar spaces of the lymphatic glands, in the meshes between the trabeculæ, and in the efferent lymphatics beyond them, the lymph also contains a certain number of white, roundish, granular cells, or *lymph-corpuscles*, *c*, having an indistinct or doubtful envelope, and a pale nucleus within, which is rendered more visible by dilute acetic acid. These corpuscles resemble, outwardly, the white blood-corpuscles; but differ from them in being only large nuclei, and not nucleated cells. Strong acetic acid only acts slightly upon them, and does not split up the nucleus into separate bodies, as is the case with the nucleus of the white blood-corpuscles. They have been observed to put out little buds, and so to become stellate, whilst they may yet be supposed to be living.

The absorbents of the small intestines, called, from their milky-looking contents during digestion, the *lacteals*, have a similar structure to the lymphatics elsewhere. They commence, however, in a peculiar way, as will be mentioned hereafter in the section on Absorption. The milky-looking fluid which they convey during digestion, is called *chyle*, and is characterised by containing multitudes of fine granules, which are minute fatty particles enveloped by an exceedingly thin film of an albuminoid substance, and constitute what has been

termed by Gulliver, the "*molecular basis of the chyle.*" Besides this, the chyle, after it has passed certain lymphatic glands, contains other granular particles, some nuclei and also a few of the pale lymph-corpuscles just described. Drawn from the thoracic duct, or from the absorbent trunks near it, the lymph, or mixed lymph and chyle, coagulates like the blood, the clot of the former being transparent, and of the latter, of a milky colour and very soft consistence. Sometimes the lymph and chyle present a reddish tinge, owing to the accidental admixture of coloured blood-corpuscles. The chyle, however, is supposed sometimes to have a proper red colouring substance formed in it: both fluids may become red on exposure to air.

The secreting membranes and glands.—The secreting membranes of the body, already generally described, are the *serous membranes*, the *synovial membranes*, the *mucous membranes*, and the *skin*. With these two latter membranes are associated the *glands*. Speaking generally, all these membranes consist of a layer of condensed areolar and elastic tissue, which is very thin in the serous and synovial membranes, thicker in the mucous membranes, and thickest of all in the skin. On its under or attached side this layer contains numerous bloodvessels, lymphatics, and nerves, all of which proceed to or from the free surface of the membrane. Near this there is found, at least in most situations, a thin stratum of a homogeneous structureless membrane, called the *limiting* or *basement membrane*. Resting upon this, or directly upon the condensed areolar layer, is invariably found a superficial stratum of *epithelial* or *epidermic* tissue, the character of which varies in different membranes, as will be presently described. The mucous membranes and the skin are much thicker, more specially organised, more vascular, and contain more nerves than the serous and synovial membranes.

The *serous membranes*, such as the arachnoid, pleura, pericardium and peritonæum, are transparent membranes arranged as closed sacs, smooth on the surface, and slightly moistened with a fluid which has been compared to the *serum* of the blood, but which resembles more closely the liquor sanguinis, for when collected in quantity it coagulates. They are covered with a single layer of flattened scale-like cells, constituting a very simple form of epithelial tissue, called the *squamous* or scaly epithelium. Fig. 43, *a*.

The *synovial membranes* lining the joints and the sheaths of tendons somewhat resemble the serous membranes, forming

like them closed sacs; but they are thicker, have a thicker epithelium, and secrete a thicker fluid,—the *synovia.* They are sometimes provided with *fringes*, or projections, called erroneously *glands* (glands of Havers). Fig. 41, *a*, 1, 3.

The *mucous membranes* do not form closed sacs, but open directly or indirectly on to the surface of the body. The chief or most extensive mucous membrane in the body is named the "*gastro-pulmonary mucous membrane*," because it forms the lining membrane of the digestive organs and the lungs. Another mucous membrane, of smaller extent, lines the urinary passages and the cavities connected with them. The former membrane commences at the mouth, extends into the nose and between the eyelids, and into certain deep parts of the ear, and then passes downwards through the air tubes into the lungs, and along the whole length of the alimentary canal. It is also extended in modified forms along the ducts of all the glands which open upon it. The mucous membranes consist of a fibro- or areolo-vascular layer named the *corium*, generally limited at its surface by a very thin transparent *basement* membrane, which again is covered by a layer of epithelial tissue. They are always of a deep red colour during life, owing to their vascularity; but being thick and somewhat opaque, as compared with the serous or synovial membranes, they often have a pale pinkish brown hue after death. Sometimes a mucous membrane is thin and smooth, as within the nose and air-passages, or it may be thicker, as inside the cheek and throat. Sometimes it is *papillated*, that is, covered with eminences called *papillæ*, as on the tongue; or *villous*, that is, provided with softer projections called *villi*, as in the small intestine; or it may be thrown into *rugæ* or ridges, as in the stomach, or developed into folds or *valves*, as in the small intestine. In some places the mucous membranes are *recessed* into little *tubes*, *follicles* or *sacs*, simple or branched, fig. 41, *b*, *c*, and so form minute *glands*; or, this formation of branched recesses being carried to an immense extent, larger compound glands are formed.

The mucous membranes secrete a slightly viscid moisture called *mucus*; and from their simple or complicated glandular recesses are formed *all the varied kinds of secretions*, such as the saliva, bile, gastric juice, tears, &c., excepting only those which come from glands similarly constructed, but existing in connection with the skin, such as the sweat glands, the sebaceous glands, and the mammary glands.

The different methods and degrees in which the surfaces of secreting membranes generally, are multiplied within a given space, are illustrated in the plans shown in fig. 41, the description of which should now be referred to.

Fig. 41.

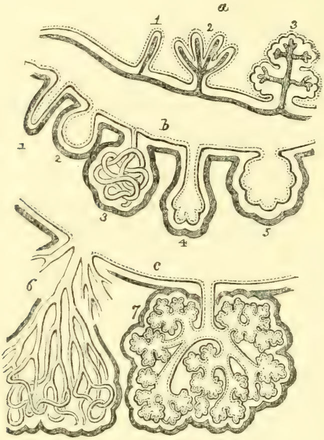


Fig. 41. (After Sharpey.) Three plans, *a*, *b*, *c*, of supposed sections of secreting membranes, to show the general arrangement of their component structures, and the way in which their surfaces are increased. In all three plans, the broad shaded line represents the areolo-vascular layer, the thin solid line is the basement or limiting membrane, and the dotted line the epithelial or covering layer. *a*, shows an increase by simple plaited or fringed projections. *b*, five modes of increase by recesses, forming five kinds of simple glands, viz. 1, a tubular follicle or *crypt;* 2, a saccular follicle or *sac;* 3, a coiled tube; 4, a *multilocular tube*, that is, a tube with depressions in it; 5, a *multilocular sac*. *c*, shows two forms of compound glands; 6, branched tubes forming a *compound tubular* gland; 7, branched tubes ending in little recesses or vesicles, forming a *compound racemose* or *conglomerate gland.*

The simple and fringed projections, *a*, 1 and 3, occur in the synovial membranes; the plaited form, 2, in the interior of the eyeball. The *simple* forms of *glands*, *b*, 1 to 5, viz. the short tubule, follicle, or *crypt*, the wide follicle or *sac*, the long *coiled tubule*, the *multilocular tubule*, and the *multilocular sac*, are met with in special organs, which we shall have hereafter to describe, as in the stomach, intestines, eyelids, nose, ear,

and skin. The *compound* forms of *glands*, *c*, are represented by the kidneys, 6, and by the mucous, lachrymal, salivary, and other glands, 7. A good example of a *multilocular sac* occurs in the follicles from the proventriculus, or secreting

Fig. 42.

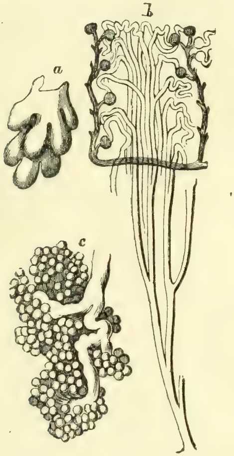


Fig. 42. *a* (Everard Home), multilocular gastric follicle from the proventriculus of an ostrich. *b* (after Kölliker), section through the substance of the kidneys, showing the branching tubuli, with their free or looped extremities, and the little rounded vascular bodies, called the glomeruli, connected with the tubuli. *c* (Müller), minute portion of the parotid gland injected with mercury, to show its terminal ducts and vesicles. All the figures are slightly magnified.

part of the stomach of the ostrich, fig. 42, *a*; an instance of a compound or branching *tubular gland* is seen in the human kidney, *b*; whilst the ultimate lobules of a salivary gland, *c*, with their terminal ducts and vesicles, form a good example of a *compound racemose vesicular gland*, or *conglomerate gland*. There is still another form of gland, in which the ducts begin by a *network*, as occurs in the liver of man and the higher animals, which may be called a *reticular* gland.

The glands are even more vascular than the mucous membranes, of which they may be regarded as extensions. It is especially to be noted that, in no case, is there any direct or

open communication between the capillary or other blood-vessels, and the terminal ducts or vesicles of the glands.

The epithelial and epidermic tissues.—These (so named from Greek words which signify that they cover other parts, viz. ἐπί, epi, upon, τίθημι, tithemi, I place, and δέρμα, the skin) are the *non-vascular* covering tissues which form and, as it were, finish off the actual surfaces of the various secreting membranes and the skin. They all consist of numerous agglutinated microscopic particles which are named *nucleated cells*, because

Fig. 43.

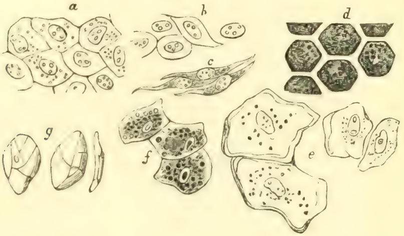


Fig. 43. (Henle and Kölliker.) Various forms of epithelium cells, magnified about 200 diameters. *a*, polyhedral squamous epithelium from the peritonæum. *b*, fusiform squamous epithelium from the interior of a vein. *c*, the same from an artery. *d*, hexagonal pigment epithelium from the black coat inside the eyeball. *e*, large squamous epithelium from the mucous membrane of the mouth. *f*, soft polyhedral glandular epithelium from the liver, or the so called hepatic cells. *g*, horny dry transparent cells of the epidermis or cuticle. In nearly all the preceding cells, nuclei, nucleoli, and granules are seen.

they are more or less vesicular, and always contain a smaller transparent body called a *nucleus*, which is itself at one time vesicular, and frequently includes one or more still smaller granules called *nucleoli* (see figs. 43 and 44). These nucleated cells vary in shape and size; they are sometimes arranged in one and sometimes in several layers, and cohere together by a minute quantity of intermediate substance.

Sometimes, as in the serous membranes, fig. 43, *a* (taken from the peritonæum), the epithelial cells are flat and polygonal, lying in a single layer, and fitting edge to edge like little scales, or portions of pavement; hence such an epithelium is called *squamous* or *scaly*, *tessellated* or *pavemented*. Sometimes the cells of the stratified epithelium, as in the lip, tongue, and conjunctiva of the eyelids, and also those of the epidermis, are

marked with fine lines, or *striated*; and again the deeper cells are occasionally covered with minute ridges and furrows, or with small spines, so as to be finely *denticulate* at their borders. In other situations, as in the interior of the veins, *b*, or arteries, *c*, the separate cells are *fusiform*. In the interior of the eyeball are certain *hexagonal* cells, *d*, which contain much dark-colouring matter, and are called *pigment cells*. The pigment in them exists in the form of minute coloured granules. Still larger scaly epithelium cells, *e*, exist in the mucous membrane of the mouth, throat and gullet, where they lie in several layers or are *stratified*. This is also the case on the inner surface of the eyelids, where the deeper cells, as shown in fig. 44, *c*, 4, are round; the next above them are oval or compressed, 3; the next somewhat flattened, 2; and the superficial ones quite thin or scaly, 1. In the epidermis, cuticle, or outer skin, which is raised in blistering any part, the cells also exist in many layers; they are quite flat, fig. 43, *g*, on the surface only, where they have a peculiar, dry, horny character. The appendages of the cuticle, viz. the nails and hair, are also formed of modified epidermoid cells. There is a peculiar kind of epithelium called *spheroidal* or *glandular*, because its soft cells, often filled with granular matter, are roundish, and are found in the glands, *i. e.* in the smallest or ultimate ducts of glands (see fig. 91): sometimes, as in the liver, the glandular epithelium cells, fig. 43, *f*, are compressed on all sides or *polyhedral*. When the spheroidal epithelium joins any other variety, whether squamous or columnar, the cells gradually change their shape accordingly, and thus is formed the *transitional* epithelium. Another form of epithelium is called *cylindrical* or *columnar*, fig. 44 *a*, *b*, from the cylinder- or column-like shape and perpendicular arrangement of its component cells. This kind is found in the stomach and on the little projections, called villi, in the small intestine. The group, *a* 1, fig. 44, shows a single row of columnar cells attached at one end; 2, six cells seen at their free ends; and 3, a single cell more highly magnified; the outer ends of these are said sometimes to be finely channelled or perforated. In certain situations, as in the air passage through the nose and throat, and in the air-tubes of the lungs, this columnar epithelium is covered with minute soft thread-like appendages named *cilia*, attached to the free ends of the cells, and is hence called *ciliated columnar* epithelium, *b*. By some the soft homogeneous substance composing these cilia is considered to be sarcodous. In

the windpipe, this sort of epithelium is *stratified* or has many layers of cells, *d*, the superficial ones only being columnar and provided with cilia. In certain cavities in the interior of the brain, the epithelium is said by the best authorities (though it is doubted by some observers) to be ciliated, but the cells are flattened, not columnar. In some animals, too, a spheroidal

Fig. 44.

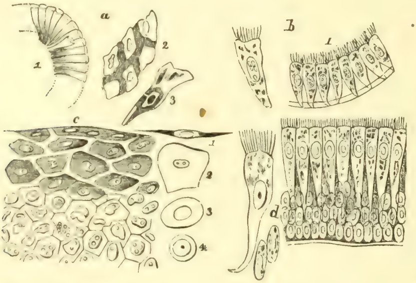


Fig. 44. (Henle and Kölliker.) Various forms of epithelium cells, magnified about 200 diameters, excepting *a*, 1, which is less magnified. *a*, columnar epithelium from the surface of a villus of the small intestine; 1, cells attached to a part of a villus; 2, six cells seen at their free ends; and, 3, a single cell viewed sideways, showing the central nucleus. *b*, row of ciliated epithelium, and a single cell enlarged, from one of the smaller air tubes. *c*, stratified squamous epithelium from inner surface of the eyelid in the calf, showing in mass and separately, 4, 3, 2, 1, the changes in form from the deep to the superficial cells. *d*, stratified columnar ciliated epithelium, with several detached cells from the mucous or lining membrane of the trachea or windpipe.

tabular epithelium is met with, having cilia upon it, as in the roof of the frog's mouth.

There are some special tissues, or modifications of tissue, such as the *teeth*, *nails*, and hair, the humours and other parts of the eye, and certain parts of the ear and nose, which will be described hereafter. The structure of the different *secreting glands* will be considered in the chapters treating of their *respective* functions; and so, likewise, will the structure of those organs which, from their general resemblance to the secreting glands, have also been called glands, viz. the *ductless* or *vascular glands*, or *blood-glands*, which include the spleen, supra-renal bodies, thyroid body, and thymus gland, and also the *closed saccular* glands of the alimentary canal, represented by those of the tongue and tonsils, by the solitary

glands of the stomach and intestines, and by the so-called Peyer's glands found in the small intestine only.

General View of the Structural Elements of the Tissues.

If now we glance generally at the numerous elementary microscopic constituents of the tissues, we find that, however varied they may be, they are all referrible to one or other of the following forms: *intermediate connecting* substance, named *blastema* or *matrix*, *crystals*, *protoplasm*, *granules*, *homogeneous* or *structureless membrane*, *vesicles*, *nuclei*, *nucleated cells*, *simple fibres*, *nucleated fibres*, *compound fibres*, and *tubes*. The blastema or matrix may be either fluid, as in the case of the liquor sanguinis of the blood, or softish, as in the moist tissues; either abundant, as in the soft forms of connective tissue, scanty, as in some epithelia, or absent, as in a peculiar reticular kind of connective tissue, found in the lymphatic glands and elsewhere; or the matrix may be dry and scanty, as in the cuticle, or abundant and fibrous, as in the connective tissues, homogeneous, as in pure cartilage, or fibrous and calcified, as in bone. Crystals are rare, except in disease. Protoplasm is the soft, minutely granular substance, so universal in both the animal and vegetable kingdoms, and the earliest recognisable form of organic matter. Separate elementary granules are present in the chyle, the blood, the brain substance, the pigment tissue, and elsewhere. Elementary vesicles, consisting of fatty matter, exist in the chyle, the blood, and the milk. Free nuclei occur in the cerebellum, and are also represented in the lymph corpuscles. Structureless membrane forms the basement membrane of the mucous tissues and glands; also the walls of certain nucleated cells, and the coats of the finest capillaries. Nucleated-cell tissues are represented by the white and early stage of the red blood-corpuscles, by the epithelial and epidermic cells, the pigment cells, the cells of the adipose tissue, and by the ganglionic corpuscles of the grey nervous substance. A nucleated cell is said to consist of an outer part or *periplast*, and certain contents, named the *endoplast*, lying in which is a *nucleus*, and within that, often, a *nucleolus*, or *nucleoli*: sometimes the periplast or envelope is indistinct or absent; and the entire cell may be soft, or firm, or even dry. Nucleated cells having an envelope, such as the epithelial cells and red blood-cells, might be conveniently termed *cystoplasts*; whilst the naked cells, without envelopes, such as the white blood corpuscles, might be named *gymnoplasts*. The

nuclei of these cells, and those found in the connective and muscular tissues, are regarded as nutritive centres, surrounded by protoplasm or germinal matter. Nucleated cells, embedded in solid blastema, occur in cartilage and in bone. Ramified or branching cells with nuclei, form the so-called connective tissue corpuscles. The fibres of the areolar, fibrous, and elastic tissues, are usually said to be produced by the fibrillation of intercellular substance. Mixtures of such fibres with cartilage cells, form the white and yellow fibro-cartilages. Nucleated cells, elongated, perhaps joined, and composed of a peculiar substance, form the unstriped muscular fibres, and the grey or gelatinous nerve-fibres of the sympathetic system. Compound fibres, themselves derived from the union and modification of several nucleated cells, occur in the highly organised striped muscular fibres, and in the white or tubular nerve-fibres. Lastly, the commencing lymphatic vessels, and the capillaries, are examples of tubular tissues derived from the junction of ramified nucleated cells. The larger bloodvessels and lymphatics, and the ducts of glands, are really compound structures, or organs, built up of several tissues: so too, of course, are the various membranes, the glands and the organs of the senses, and such large organs as the brain, heart, and lungs.

Size of the Structural Elements of the Tissues.

Perhaps the best practical notion may be formed of the extremely minute size of the objects we have just been considering and describing, by reflecting on the statement that the red blood corpuscles of man are on an average $\frac{1}{3300}$ of an inch in diameter, and about $\frac{1}{4}$th of that or $\frac{1}{13000}$th of an inch in thickness: in other words, 3300 of these little bodies placed side by side would occupy one inch in length, and 13,000 piled one on the other would stand just an inch high. About 1300 red corpuscles would be necessary to cover the dot of this letter i, and upwards of ten millions to cover a square inch of paper. A cubic centimetre, or $\frac{6}{100}$ths of a cubic inch, of human blood contains upwards of 5,000,000 of red, and 14,000 of white corpuscles. (Vierordt.) The red blood corpuscles may be taken as a rough standard of comparison in measuring all the other microscopic objects met with in the tissues; but these corpuscles vary in size, even in the same person, some being as much as a third larger or smaller than the average. The following is a list of the chief objects,—with their respective *average* diameters in parts of an inch.

They are arranged nearly in the order of their complexity of organisation.

	Average size in parts of an inch.
Granules of the chyle	$\frac{1}{30000}$
Corpuscles of the chyle and lymph	$\frac{1}{2500}$
,, of the blood, white	$\frac{1}{2500}$
,, ,, red	$\frac{1}{3300}$
Epithelial cells of peritonæum—squamous	$\frac{1}{1000}$
,, mouth—ditto	$\frac{1}{600}$
,, intestines—columnar (length)	$\frac{1}{2000}$
,, trachea—ciliated (length)	$\frac{1}{2000}$
Cilia (length)	$\frac{1}{3000}$
Epidermic cells	$\frac{1}{800}$
Pigment cells of eyeball—hexagonal	$\frac{1}{1000}$
,, granules	$\frac{1}{20000}$
Fat cells	$\frac{1}{450}$
Nuclei of cartilage cells	$\frac{1}{3000}$
Canals of Havers in bone (medium size)	$\frac{1}{500}$
,, (extremes)	from $\frac{1}{1000}$ to $\frac{1}{200}$
Lacunæ or bone corpuscles (width)	$\frac{1}{3600}$
,, (length)	$\frac{1}{1800}$
Canaliculi of bone (width)	$\frac{1}{7000}$
Connective fibres	$\frac{1}{15000}$
Elastic fibres	from $\frac{1}{20000}$ to $\frac{1}{4000}$
Unstriped muscular fibres	from $\frac{1}{7000}$ to $\frac{1}{3500}$
Striped muscular fibres (male)	$\frac{1}{350}$
,, (female)	$\frac{1}{450}$
Filaments of these fibres	$\frac{1}{10000}$ to $\frac{1}{18000}$
Ganglionic corpuscles of brain	from $\frac{1}{3000}$ to $\frac{1}{300}$
Grey nerve fibres	$\frac{1}{5000}$
White tubular nerve fibres (medium)	$\frac{1}{6000}$
,, (extreme)	from $\frac{1}{12000}$ to $\frac{1}{1500}$
Terminal non-medullated nerve fibres	$\frac{1}{10000}$
Capillaries, large, in bones	$\frac{1}{1200}$
,, small, in lungs	$\frac{1}{3000}$
Lymphatics of skin	$\frac{1}{800}$

Red Blood Corpuscles in Animals.

Mammalia.

Elephant	$\frac{1}{2700}$
Sloth	$\frac{1}{2800}$

(Human corpuscles, $\frac{1}{3300}$)

	Average size in parts of an inch.
Ape	$\frac{1}{3400}$
Dog	$\frac{1}{3500}$
Wolf	$\frac{1}{3600}$
Ox	$\frac{1}{4200}$
Cat	$\frac{1}{4400}$
Horse	$\frac{1}{4600}$
Deer	$\frac{1}{5000}$
Sheep	$\frac{1}{5300}$
Goat	$\frac{1}{6300}$
Musk Deer	$\frac{1}{12000}$
Birds.	
Various species (length)	$\frac{1}{1700}$ to $\frac{1}{2400}$
Reptiles.	
Various species (length)	$\frac{1}{1200}$ to $\frac{1}{1500}$
Amphibia.	
Frog (length)	$\frac{1}{1000}$ to $\frac{1}{1200}$
Siren (length)	$\frac{1}{420}$
Proteus (length)	$\frac{1}{330}$
Fishes.	
Various species (length)	$\frac{1}{1150}$ to $\frac{1}{2450}$

SPECIFIC GRAVITY OF CERTAIN ANIMAL FLUIDS AND TISSUES, WATER BEING 1000 DEGREES.

Chyle	1024
Lymph	1037
Blood	1052 to 1057
„ Serum	1028
„ Red corpuscles	1088
Adipose tissue	932
Brain substance (white)	1009
„ „ (grey)	1030
Muscular tissue	1020
Cartilage	1150
Bone	1870 to 1970
The entire body	1065

The specific gravity of the glandular organs and their secretions is given with the descriptions of those parts and fluids.

THE PHYSICAL PROPERTIES OF THE TISSUES.

It is scarcely necessary to state here, that the materials of the body have all the physical properties of matter generally, such as weight, cohesion, extensibility, inertia, impenetrability, and so forth. Specially, however, we have to notice that, with the exception of the extreme outer layer of the cuticle, and the hairs and nails, every part and tissue of the body is *moist*. Even those parts contain a small quantity of water. With the above-mentioned partial exceptions, all the tissues are exceedingly *permeable* to that element or to solutions of which water is the main constituent; and when dried, as may be exemplified in the case of a piece of dried flesh, tendon, or bladder, they very greedily reabsorb their lost quantity of fluid, when placed in circumstances in which they can do so.

The physical characters of all the animal tissues, indeed, are largely, nay essentially, dependent on the presence of the water contained, not only in the fluids or intermediate moist blastema, but also in the very substance of the more consistent tissues. Thus, it is their *contained* or *essential* water which endows all the soft textures, membranes, and organs with the requisite *suppleness*, *flexibility*, and general *elasticity* or *resiliency;* whilst their relative *mobility* amongst or over each other, is secured by their different degrees of *softness*, and by the presence of the intermediate moisture. The toughness or *cohesiveness* of all the consistent tissues, even of bone itself, also demands a certain proportion of combined or constituent water. Finally, the *special* or peculiar india-rubber-like *elasticity* possessed, and exhibited, even after death, by the hence so-called yellow elastic tissue, is a purely physical property, which is manifested only so long as the tissue itself retains a sufficiency of its combined water.

The remarkable *permeability* of the animal tissues, and, we may add, of vegetable tissues also, to water and watery solutions, is a character which, physically considered, is, to a certain extent, dependent on the previous natural existence of water in them; for had they been saturated with some other fluid, as oil for example, they would have resisted the percolation of water and watery solutions. The phenomena attending the passage, in opposite directions, of water, and of various substances dissolved in that fluid, through dead organic

membranes, described by Dutrochet under the designations of *Endosmosis* and *Exosmosis*, and more recently by Graham, under the terms *Osmosis* and *Dialysis*, will be considered in the chapter on Absorption.

THE CHEMICAL COMPOSITION OF THE BODY.

If the tissues and organs of the body are subjected to various processes of chemical analysis,—either by being allowed to coagulate, or by being coagulated by means of heat; by being washed or boiled in water for a long time, or by being dried and treated with alcohol and ether, certain products being then obtained by filtration and evaporation; or lastly, by being burnt to ashes,—it is found that they yield a number of substances which are called the *proximate constituents* of the body, because they are the first chemical compounds into which the several tissues may be made to resolve themselves. Some of these being peculiar to organised bodies are named accordingly, the *organic proximate constituents*; whilst others, found in the mineral kingdom also, are called the *inorganic proximate constituents.* The former, however, are by putrefaction or destructive heat, still further decomposed into ultimate chemical elements, which themselves belong to the mineral kingdom.

The Proximate Chemical Constituents of the Body.

The chief *inorganic* proximate constituent of the body is *water.* Next to this in quantity is *phosphate of lime.* Then the *carbonate of lime*, *chloride of sodium* (common salt), *chloride of potassium*, *phosphates*, *sulphates* and *carbonates of soda and potash*, *phosphates* and *carbonates of magnesia*, *fluoride of calcium*, and certain compounds containing *iron*, *silica*, and *manganese*, besides traces of probably accidental substances, such as copper, lead, and aluminium. To these we must also add *ammonia*, which exists in combination in the urine, and likewise the gases named *carbonic acid*, *oxygen*, and *nitrogen.*

The *organic* proximate constituents are of two kinds. One kind contains the chemical element azote or nitrogen, and is hence called *azotised* or *nitrogenised.* These readily decompose and yield ammonia when they are burnt or putrefied. They are albumen and its allied substances, vitellin, globulin, and fibrin,—gelatin, chondrin, and elastin—mucus and horny

natter,—extractive matters, crystallisable and non-crystal-lisable,—colouring matters, red and black,—a peculiar acid found in the brain, — the products of certain glands, such as casein, pepsin, salivin, and pancreatin (all of which are more or less allied to albumen),—and, lastly, the biliary matters, and urea and uric acid. Another kind, not con-aining nitrogen, and hence called *non-azotised* substances, ncludes fatty matters of various kinds, blood- or liver-sugar, ugar of milk, sugar of muscle, lactic acid, and certain ngredients of the bile.

The azotised substances, generally, may be classed into the *lbuminous* and *gelatinous* matters, *colouring* and *extractive* natters, and *secretory* or *excretory* substances. The non-zotised, taken generally, are either *oleaginous*, *saccharine*, or *cid* substances. The general characters of the chief of these ubstances will be first pointed out, and the constitution of the rincipal tissues will then be described.

Azotised Substances.—Albumen is the well known substance which forms the *white* of eggs, whence its name, from *albus*, white. Natural albumen is soluble in water, and indeed ex-ists largely in a state of solution in the blood of animals and nan. It is then transparent, and may be dried at low tem-eratures into an equally transparent brittle mass. Its solu-ility appears to be somewhat increased by the presence of hloride of sodium (common salt), and perhaps of the alkaline hosphates and carbonates, in the blood. When, however, it is ubjected to a heat of 142°, or, if in solution, to a heat of 158°, coagulates or sets into an opaque white substance, which is enceforth insoluble in water. In solution, albumen is preci-tated by alcohol, strong acids, and most metallic salts. When agulated, it is dissolved by weak acids in excess, and by rong alkalis, and it is hardened by alcohol. Albumen is und chiefly in the fluid part of the blood, in the substance the brain and nerves, and in the moisture which pervades e muscular and other tissues of the body: it exists also in e secretions of serous and synovial membranes, and in the mph and chyle. A peculiar form of albumen, called *globulin*, the chief constituent of the red corpuscles of the blood. lbumen is probably the root or source of all the other azotised gredients of the body, and, together with fat, is the great nu-tive substance of the animal economy. Vitellin is a modi-ation of albumen, which is found in the yolk of the egg. It thrown down by even weak acids.

Fibrin is the soft, whitish *stringy* substance which is obtained from freshly drawn blood, by beating or whipping it with a bundle of fine sticks or wires. It is closely allied to albumen, but differs from it in the very remarkable and singular property of *self-coagulation*, or *spontaneous coagulation*. In the act of coagulation, it concretes into minute threads or *fibrils*; whence its name. The nature of this process is not yet understood; it will have to be discussed hereafter. Fibrin is present in a state of solution, though, as compared with albumen, in very small proportion, in the fluid part of the blood; but it speedily coagulates when the blood is drawn from its vessels, and indeed is the material part concerned in the coagulation or clotting of the blood. Traces of dissolved fibrin also exist in the fluid of the chyle and lymph, and in the serous fluids. But it is in the muscular tissue that so enormous a quantity of a peculiar kind of fibrin is found, which is named *fibrin of muscle*, or *syntonin*, from συντείνω, *sunteino*, I contract. Like albumen, fibrin is precipitated, and then hardened, by alcohol: it is precipitated by mineral acids and most metallic salts; but is re-dissolved by dilute acids in excess. Blood-fibrin is soluble in a solution of nitre, but syntonin, or muscle-fibrin, is not. In the living body, as we shall hereafter find, both albumen and fibrin exist, sometimes in the solid and sometimes in the liquid state.

Gelatin is the substance of jellies, size, and glue. It is not proved to exist as gelatin in the living or dead body; but it is obtained as a product rather than as an educt, by boiling in water any part which contains white connective tissue, such as the areolar tissue, tendons, ligaments, the skin and the areolar basis of the membranes generally. It is also obtainable from the animal matter of bones by long continued boiling under pressure, as in a Papin's digester. From cartilages of a pure kind, a peculiar variety of gelatin, called *chondrin*, is extracted by boiling in water. No gelatin can be obtained by boiling blood, chyle, bile, gastric juice, saliva, milk, brain substance, or muscle, except in the latter case, such as is derived from areolar tissue. Gelatin and chondrin do not coagulate. Gelatin, as its name implies, *gelatinises* on cooling, and is liquefied or dissolved again by heat. One part of gelatin will gelatinise a hundred parts of water. Chondrin is also said to gelatinise, but this is doubtful. Neither gelatin nor chondrin is precipitated by the red or yellow prussiates of potash, by which they are distinguished from albuminoid bodies. They

are, however, precipitated by alcohol, ether, corrosive sublimate, and by tannic acid or tannin, which is the active substance in converting any gelatin-yielding tissue, such, especially, as the skin, into the firm insoluble substance which we call *leather*. Chondrin is distinguished from gelatin, by being precipitated by acetate of lead, alum, acids, and a few salts, which do not throw down gelatin.

Keratin, or horny matter, exists in the hair, nails, and epidermis or cuticle, and also in the denser epithelia. *Mucin* exists in mucus, which is almost always acid.

Hœmatin, from *αἷμα*, *haima*, blood, is a red colouring matter, which is extracted from the red blood-corpuscles, with the globulin of which it is most intimately united. The compound formed by these two substances, named *hœmato-globulin*, has a great tendency to crystallise, even in blood simply set aside, but still more so in blood subjected to the successive action of oxygen and carbonic acid. The crystals from human blood are either prismatic or rhombic ; from animals, tetrahedral, rhombohedral, and hexagonal crystals have been obtained. They are doubly refractive, soluble in acetic acid, ammonia, and water, and even deliquescent; but they are insoluble in alcohol. In blood extravasated within the body, there are frequently found flat, rhombic crystals, insoluble in water, acetic acid, alcohol, or ether, but soluble in chloroform. These are named *hœmatoidin*, the reactions of which with sulphuric acid resemble those of the bile pigments with nitric acid. Other crystals, named hæmatin and hæmin, have also been artificially obtained from blood. The so-called *hœmatin* is a deep red, almost black, substance, insoluble in water, alcohol, and ether, unless these be acidulated; it is readily soluble in alkalis. It contains a very large quantity of iron, nearly 7 per cent., but its colour does not depend on the presence of this mineral. Hæmatin is now supposed to be a product of decomposition of the true colouring substance of the blood, which is named *cruorin*, and has a peculiar action on the solar spectrum. The green and yellow colouring matters of the bile, *biliverdin* and *bilifulvin*, seem to be somewhat allied to hæmatin.

Black or brown *pigment*, as found in the eye and in the negro's skin, is also peculiar in its composition. Both it and the hæmatin of the blood, have their colour discharged or bleached by chlorine.

Casein exists in solution in fresh milk, and forms the substance

of the curd of milk, and therefore of *cheese* (caseum), in which, however, it is mixed with more or less fatty matter or butter. Casein is very like albumen in its general properties, but, when pure and by itself, it will not coagulate by boiling. Its solubility appears to depend greatly on the presence of some alkaline or earthy salt having an excess of base. The pellicle which forms on the top of boiling milk is, in some way, owing to the action of the atmospheric oxygen. Acids, even when much diluted, readily coagulate it, hence the curdling of sour milk, in which lactic acid is developed; but its characteristic reaction is rapidly to coagulate by the addition of *rennet*, or the prepared mucous membrane of the fourth stomach of the calf: this is what takes place in the manufacture of cheese.

Pepsin is a very remarkable and potent albuminous substance, which exists in the gastric juice or secretion from the mucous membrane of the stomach of man and animals, and also in that membrane itself. From this it may be extracted by cold water, in which it is sparingly soluble. When slightly acidulated, especially by dilute hydrochloric acid, a solution of pepsin in water, at a low heat, rapidly brings about the solution of coagulated albumen, blood, and muscle-fibrin, meat, fish, cheese, and many other aliments. It does not dissolve the epidermoid or horny tissues, or the yellow elastic tissue, or pure fat. Its marvellous solvent property, or property of causing albuminous substances to dissolve in weak acids, is, as we shall hereafter see, the source of the digestive power of the gastric juice. The peculiar properties of pepsin are destroyed by a boiling temperature, and by alkalis. Pepsin is precipitated in whitish flocculi, and rendered inert by alcohol; but the precipitate regains its solvent power when washed or again soaked in large quantities of water.

Salivin, or *ptyalin*, is a peculiar albuminoid substance found in the saliva. It has the very remarkable property (not altogether peculiar to it however), of almost instantaneously converting starch into a kind of gum called dextrin, the dextrin into a form of sugar, and this sugar very soon into lactic acid. *Pancreatin* is the active principle of the secretion of the pancreas, which seems to possess the power of emulsifying fat.

The *extractive matters* mentioned above, in the list of azotised substances of the body, are yet but imperfectly understood. Amongst the crystallisable substances formerly confounded

under that title, may now be reckoned *creatin* and *creatinin*, both of which exist in the juice of muscle and in the blood. The latter is also found in the renal excretion or urine, whilst the former occurs in the brain. Another substance, named *sarcin*, *sarcosin*, or *hypo-xanthin*, is also found in the flesh and the blood. *Xanthin* occurs probably in all the soft tissues, and in the urine; it is allied to *guanin*. *Leucin* is another of these compounds, supposed to be the products of metamorphoses of albumen, and present in minute quantity in the body generally. *Tyrosin* occurs only in disease.

Amongst the azotised substances occurring in parts of the body only, must be mentioned one, named *cerebric acid*, which exists in the grey substance of the brain; and also the *cholic* or *glycocholic*, and the *taurocholic acids*, which are ingredients of the bile. These acids break up respectively, into *cholalic acid* and *glycocoll* or *glycocin*, and the same acid and *taurin*. Lastly, in the renal excretion, there are found large quantities of the substances called *urea* and *uric acid*, minute traces of which occur in the blood and soft tissues generally. *Urea* is a white crystallised substance, exceedingly soluble in water, to which it imparts a saline taste. It is remarkable that, though a product of living animals, it can be made artificially from organic matter, and is then known as a *cyanate of ammonia*, that is, a salt consisting of cyanic acid and ammonia. It acts as a base itself, however, and is capable of uniting with acids to form highly compound salts. *Uric acid*, normally existing in a state of solution in combination with ammonia or other bases, is easily precipitated in the form of minute crystals, and then is very insoluble. It constitutes the most common form of gravel and stone (hence its other name *lithic acid*, from λίθος, lithos, a stone), and is even excreted in a semi-solid form in birds, and in a solid form in serpents. *Hippuric* acid is said also to occur in human blood and urine; it exists largely in the urine of herbivorous quadrupeds.

Non-azotised Substances.—Of these, by far the most abundant are the various *fatty* matters, which are all distinguished by being insoluble in water, but soluble in pure hot alcohol and in ether. The principal seat of these fats is, of course, the adipose tissue; but fatty matters are found also in the brain and in muscle, in the blood, and especially in the chyle. The fat of the human body consists chiefly of olein, with a little so-called margarin dissolved in it. *Olein* is a fluid fat or oil, similar to that which constitutes the basis of olive, and some other oils.

By being boiled with an alkali, as in the manufacture of soap, olein is separated into a fatty acid, called *oleic acid*, and a sweet viscid substance called *glycerin*, which of late years has become so familiar to all. *Palmitin* is a solid crystallisable fat, which is decomposable into *palmitic acid* and glycerin. In the fat of the sheep and ox, there is a third still more solid fat, *stearin*, which may be separated into glycerin and *stearic acid*. Margarin, another solid fat, is now supposed to be a mixture of stearin and palmitin. A fourth fatty substance, found in the brain, is named *lecithin*. Margarin melts at 114°, and stearin at 118°; whilst olein is fluid at ordinary temperatures, but solidifies at 50°.

Oleic, *butyric*, and probably some other volatile fatty acids, *propionic* and *caproic*, exist in the milk.

The so-called *glycero-phosphoric* acid is found in the brain: it is formed of phosphoric acid and glycerin. The phosphorus of the brain has also been regarded as occurring in combination with oleic acid, as an *oleophosphoric acid*; but this is doubtful.

Cholesterin is a sort of animal resin, which crystallises in beautiful microscopic white scales. It occurs chiefly in the brain and in the bile, and forms the substance of most gall-stones. It also accumulates in certain *morbid fluids* and *diseased tissues*.

Starch and sugars of different kinds are found in the body. Thus, there is either an amylaceous, *sugar-forming* or *glycogenic* substance, named *amylin*, *glycogen*, or *hepatin* (from γλυκύς, *glūcūs*, sweet, and γείνομαι, *geinomai*, to become), or else a kind of sugar, named *glucose*, *dextrose*, or *grape-sugar*, in the liver, and in the blood of the veins which leave that organ. There is another kind of sugar in muscle, called *inosite*. Lastly, in milk, there is a large quantity of *lactin* or *sugar of milk*, which, in solution and in contact with azotised matter or a ferment, easily decomposes, and forms *lactic acid*, as happens in the souring of milk.

Lactic acid itself is also found in the blood as a lactate of potash or soda, in muscle, in the perspiration, and in the renal excretion. It is met with also in the gastric juice.

Formic and *acetic* acids exist in the perspiration, and sometimes *oxalic* acid in the urine.

The above-named saccharine and acid substances are all soluble in both water and alcohol.

The Chemical Composition of the several Tissues.

Such being the characters of the principal proximate organic and inorganic constituents of the animal body and its various fluids, it must be understood that these various substances may be extracted from, or shown to exist in, the different tissues, in certain definite quantities; in other words, that they may be obtained separately from each other, by taking advantage of their different behaviour when acted on by water, alcohol or ether, by evaporating their respective solutions in those fluids, and by drying or burning the tissues themselves. For example, the composition of the white substance of the brain is ascertainable by some such process as the following:—

A given weight, sufficiently large to cover small errors, is first dried, at a temperature of 212°, in a water bath, so as to show, by the loss through evaporation, the quantity of *water* it contained. The dried mass, cut or broken up, and then acted on by successive portions of ether, will yield to that fluid its *fatty matters*, which may be obtained separately, so as to be weighed, by allowing the ethereal solutions drawn off from the undissolved residue to evaporate spontaneously. Those residual undissolved matters acted on successively by hot alcohol, will yield to that menstruum, besides further traces of fat, certain *extractive matters* and *salts* (chlorides of sodium and potassium), which may be obtained by evaporating the alcoholic solutions, and would then have to be separated by special processes, and be weighed. The undissolved residuum, now acted on by boiling water, will yield to that fluid more *extractive matters*, and more *salts* (chiefly phosphates of soda and potash), which would have to be separated and weighed. The residue this time (insoluble in either ether, alcohol or water), would consist chiefly of an *animal substance*, which would be found to be of an *albuminoid* nature, mixed however with *earthy constituents*. It would have again to be dried at 212° to expel the water, and then be weighed. This dried mass being now burnt in a covered vessel, the loss would indicate the quantity of albuminoid matter, whilst the ashes would consist of the earthy salts (phosphates, carbonates, and sulphates of lime and magnesia), which would finally have to be separated by ordinary chemical processes, and be weighed. In this way, all the proximate constituents of the white brain substance,

and their relative quantities, would be, though, after all, roughly ascertained.

We shall now briefly indicate the chemical constitution of the various tissues, reserving to special occasions the details of the composition of the different secretions.

The *connective tissues*, areolar, fibrous, tendinous, and membranous, including the basis of the skin, contain about two-thirds of water, and one-third of solid matter. The solid matter is nearly entirely resolved into gelatin on being boiled, but, like the blood itself, contains traces of alkaline and earthy salts.

Permanent cartilage contains about three-fifths of water and two-fifths of solid matter, which is resolved into chondrin on boiling. The solution gelatinises on cooling, perhaps from the presence of a little gelatin. This cartilage contains from 3 to 4 per cent. of alkaline and earthy salts, chiefly carbonate and sulphate of soda, and carbonate of lime, but it also contains chloride of sodium and phosphate of magnesia and lime. *Temporary cartilage* yields a solution of chondrin, which does not gelatinise.

The *fibro-cartilages* have a mixed composition, yielding both gelatin and chondrin on being boiled. The *yellow elastic* tissue is said to contain less water than the other soft tissues. It offers great resistance to the action of boiling water, but at last yields, together with some gelatin, a peculiar substance named *elastin*, unlike both gelatin and chondrin; about one-half, however, is insoluble.

Recent *bone* contains nearly 10 per cent. of water. The animal part of dried bone constitutes 33 per cent., or one-third of its weight, and is convertible into gelatin on being boiled. The remaining two-thirds, or 66 per cent., are inorganic or mineral matters, and consist of 51 parts of tribasic phosphate of lime (or bone earth), and 11 parts of carbonate of lime (chalk); the rest (a very small proportion) is fluoride of calcium (fluorspar), phosphate of magnesia, and chloride of sodium (common salt). The compact bony substance contains more earthy matter than the spongy bone; and also proportionally more phosphate to the carbonate of lime than the latter. In old age, the bones have been said to contain proportionally more earthy matter, but this is doubtful. In the disease called rickets, they contain less. In children, the carbonate of lime is, relatively to the phosphate, less abundant.

The purest form of the *muscular tissue*, the substance of the

voluntary muscles, contains about 74·5 per cent., or nearly three-fourths of its weight of water. The remaining fourth, or 24·5 per cent., which is solid matter, consists of 15 parts of muscle-fibrin or syntonin, and of a residue, of which from 2 to 4 parts are fat, the rest being albumen (probably derived from moist fluid between the fibres, and the blood in the capillary vessels of the muscle), gelatin (derived from the intermixed fine areolar tissue), traces of a red pigmentary substance, a large quantity of extractive matters, such as creatin and creatinin, muscle-sugar or inosite, lactic, butyric, formic and acetic acids, and a quantity of alkaline and earthy salts, with some carbonic acid and oxygen. The juice of muscle is acid. It contains more potash than soda salts, a large proportion of which are phosphates. The substance formerly called *osmazome*, on which the odour of muscle depends, is a compound of several of the extractive matters.

The *white* and *grey nervous substances* resemble each other in containing, like the rest of the soft tissues, a very large percentage of water; the solid residue is composed of albuminoid matter, a large quantity of fatty matters, extractives, and salts. They differ from each other remarkably, in the relative proportions of their constituents. The white substance contains more solid matter and less water than the grey,—the percentage in the white matter being 73 of water to 27 of solid substances, and in the grey matter 85 of water to only 15 of solids. The white matter contains 15 per cent. of fat, the grey only 5 per cent.: the white has 10 per cent. of albuminous matters, the grey only 7½: the extractive matter and the salts are about the same, the latter being chiefly phosphates. Amongst the albuminoid substances, is one said to resemble syntonin, and another which is compared to elastin. The fatty matters are partly reddish and partly colourless: they consist of cerebric acid (a peculiar azotised acid), glycero-phosphoric acid, lecithin, palmitin, palmitic acid, with traces of olein, and some cholesterin. These fatty substances are supposed to be chiefly present in the medullary sheath, whilst the axis band is believed to contain the albuminoid syntonin. The extractives consist of creatin, xanthin, hypo-xanthin or sarcin, and inosite, with lactic, phosphoric, and even uric acids, combined with potash, lime, and magnesia. There are also traces of oxide of iron, silica, alkaline sulphates, and chloride of sodium. The phosphorus specially contained in the brain, amounts to from 1·3 to 1·79 per cent. of the weight of its substance.

The proximate constituents of the *blood* are so various, that, chemically speaking, it contains nearly all the substances found in the solid tissues, either as its essential constituents, or as unavoidable or occasional impurities. There is one very remarkable exception to this statement, in the total absence from the blood of any gelatin or chondrin, or of any substance which yields gelatin or chondrin on being boiled. In this respect, blood resembles pure muscular tissue and nervous tissue, and differs from the connective, cartilaginous, and osseous tissues. Blood has, indeed, been called *liquid flesh*, and it contains nearly as much solid matter as flesh, for the blood contains one-fifth, and muscle one-fourth, of its weight of solids. The analyses of the blood by various chemists, present very different results, partly due to the different methods employed, but also, doubtless, to the variable composition of this fluid under different conditions connected with health, exercise, food, temperament, age and sex. Venous and arterial blood likewise differ in certain respects. The following table from Lehmann shows the composition of 1000 parts of blood, calculated from the analysis of venous blood by Lecanu:

	Corpuscles.	Plasma.	Total.
Water . . .	344·	451·45	795·45
Hæmatin . . .	8·375	—	8·375
Globulin and Envelopes	141·11	—	141·11
Fat	1·155	·86	2·015
Extractive Matters .	1·3	1·97	3·27
Salts	4·06	4·275	8·335
Fibrin	—	2·025	2·025
Albumen . . .	—	39·42	39·42
	500·	500·	1000·

According to this estimate, blood contains about 80 per cent. of water, and 20 of solid matter, the calculated proportions being about 79·5 and 20·5. In round numbers, of the 205 parts of solids, 156 belong to the red and white corpuscles, and consist of 141 parts of globulin (modified albumen), $8\frac{1}{2}$ parts of hæmatin, the red colouring substance, 1 part of fat, $1\frac{1}{2}$ of extractive matters, and 4 parts of salts, chiefly salts of potash. The remaining 49 parts of solids belong to the liquor sanguinis, plasma, or fluid part of the blood, and include rather more than 2 parts of blood-fibrin, which goes with the corpuscles in the act of clotting: the rest of these solids are proper to the serum of the blood, and consist of $39\frac{1}{2}$ parts of albumen, 1 of fat, 2 of extractive matters, and $4\frac{1}{2}$ of salts, chiefly salts of soda. Salts of lime and magnesia also exist in

the blood, and likewise traces of silicon and manganese, and even of lead and copper. The soda, potash, lime, and magnesia, are variously combined, so as to form chlorides, phosphates, sulphates, lactates, and carbonates (at least when the blood is burnt to ashes). The distribution of the mineral substances in the blood is peculiar. Thus, the moist red corpuscles contain ten times as much potassium in 1000 parts as the liquor sanguinis, but only one-third as much sodium; whilst about six times more phosphoric acid may be obtained from the corpuscles than from the liquor sanguinis, but only about half as much chlorine. The chloride of sodium is, therefore, chiefly contained in the fluid plasma of the blood, and the phosphoric acid principally, and the potassium almost entirely, in the corpuscles, which also contain a large share of the fatty matters. In carnivorous animals, phosphates preponderate in the blood; in herbivora, carbonates abound; but the chloride of sodium is very constant in both, showing the strong affinity of the animal tissues for that salt. The albumen of the blood is by some believed to be combined with soda, as a so-called albuminate. The blood has a saline taste, and is an alkaline fluid, its alkalinity depending either on a carbonate or an alkaline phosphate of soda. The crystallisable extractive matters of blood consist chiefly of creatin and creatinin, but also include hypoxanthin or sarcin, leucin, tyrosin (in disease), hippuric acid, and even urea and uric acid in minute quantities. There are also, in certain kinds of blood, traces of grape-sugar, or of the amyloid substance, glycogen, as in the blood of the hepatic veins, vena cava inferior, right auricle, and pulmonary artery. All blood contains traces of colouring substances like those of the bile, and odoriferous substances like those of the flesh. The odour of blood differs in different animals; in man it is said to be sometimes garlicky: it is supposed to be due to a fatty acid, and may be rendered more distinct by the addition of sulphuric acid, even to old specimens of dried blood. Lastly, the blood contains carbonic acid, oxygen, and nitrogen gases, in various proportions in different kinds of blood, and held in solution, or in some feeble state of combination, as will be more fully explained in the chapter on Respiration. The fluid plasma, which pervades all the tissues, must also hold in solution nearly all the constituents of the blood, including the gases just enumerated. Whilst the solid and liquid constituents of the blood are its nutrient part, the oxygen dissolved, or otherwise loosely combined in it, is its

most energetic chemical and stimulating ingredient. The special uses of its several constituents will be considered in the chapter on the Circulation.

The *chyle* and *lymph* have a similar composition to blood, but they are both much more watery, and contain far less solid matter, the chyle being the richer of the two, that is to say, during digestion; but during fasting it has the same composition as the lymph. Chyle taken from a donkey has been found to contain about 900 parts, and human lymph about 970 parts, of water in 1000. The 100 parts of solids in the chyle were found to consist of 36 of albumen, 4 of fibrin, 36 of fat, 15 of extractive matters, and 9 of salts. The 30 parts of solids in the lymph, consisted of $4\frac{1}{2}$ parts of albumen, 5 parts of fibrin, $2\frac{1}{2}$ of fat, 3 of extractive matters, and 15 of salts. Other analyses give different results; but the chyle, speaking generally, is distinguished from lymph, by containing more albumen, and much more fat; hence, after coagulation, the serum of chyle is more fatty than that of lymph. In comparison with blood, chyle contains much less albumen, but much more fat, and usually no colouring matter. The lymph of the lymphatics contains traces of sugar and urea; in the lymphatic glands leucin has been detected. The salts of the blood, chyle, and lymph, are very similar, only those of the blood are richer in phosphates. The lymph, like the blood, has a saline taste, and is alkaline; but the chyle is sometimes neutral, or only slightly alkaline.

The *serous* and *synovial epithelia* differ probably but little from albuminous substances; but the mucous epithelia, consisting of mucin, have more decided characters, approaching those of horn. The *epidermis*, and its appendages, the *nails* and *hairs*, consist chiefly of keratin with a little fat. Their ashes contain lime and iron, and those of the hair, traces even of silicon and of the metal manganese.

The chemical composition of the teeth, of the different glands, and of the various *secretions*, will be mentioned, with their uses and actions, in the physiological section of this work.

In reviewing what has been said concerning the proximate chemical substances which compose the various tissues of the body, one cannot fail to be struck with the fact that, with the exception of bone, in which the quantity is small, water enters so largely into the constitution of them all. Indeed, accord-

ing to Moleschott, it forms about 68 parts out of 100 in the entire human body. The remaining 32 parts per cent. of dried substances consist, in round numbers, of 15 parts of albuminoid bodies, including albumen, globulin, syntonin, fibrin, and colouring substances, 5 parts of gelatinous and chondrinous substances, 2·5 of fatty matters, ·5 of all the different extractive substances, including organic acids, sugar; and urea, and, lastly, of 9 parts of salts, of which 1 perhaps is alkaline, and 8 are earthy.

The albumen and globulin are found, as will have been noticed, chiefly in the blood, chyle, lymph, nervous substance, and muscle; the syntonin and fibrin in the muscles, the blood, the chyle, and the lymph; the colouring matters in the blood, the eyes, the hair, and the bile; the gelatinous and chondrinous substances in the areolar and fibrous connective tissues, in the skin, the bones, and the cartilages; horny substances in the epidermis, nails and hairs; fatty substances in the adipose tissue, the brain, the blood, the chyle, and the bile; and extractive matters in most of the tissues and organs of the body. Of the alkaline and earthy salts, all occur in the blood; but the lime salts are found principally in the bones and teeth, and much more scantily in cartilage; the magnesia salts occur in the bones, in the muscles, and in the blood; the soda salts, especially the chloride of sodium, in every tissue, but markedly in the blood-plasma; whilst the potash salts are found in the blood-corpuscles, and in the muscles. The fluoride of calcium exists in the bones, in the teeth, and in milk; silica chiefly in the bones and the hair; and iron principally in the blood. Carbonic acid and oxygen must occur everywhere, but mainly in the blood.

As to the water, combined in various measure with every tissue of the body, it is just as important, in regard to their chemical constitution and reactions, as we have seen it to be in reference to their physical characteristics, such as their softness, elasticity, and permeability. This *contained* or *essential* water, or *tissue water*, as it might be called, also facilitates in an extraordinary manner, by its universal solvent power, all the requisite and incessant chemical changes which, we know, take place, not only in the more fluid, but also in the most solid parts of the living body. It is probable, also, that, just as in certain aqueous solutions of salts or other substances, the water appears often to be chemically combined with those substances, and not to be a mere solvent, so, in the changes

from the solid to the fluid, or from the fluid to the solid state, of certain constituents of the body, water enters into combination with them, or leaves its state of combination with them, in definite proportions at various times. The vast importance of the chemical play of water in the living animal body, will be fully illustrated, as we proceed with our account of its vital properties and actions.

The subjoined Tables (from Dalton) show the quantities of water, of chloride of sodium, and of phosphate of lime, contained in 1000 parts of certain tissues, fluids, secretions, and excretions of the body. Some of these have not yet been here described.

Water, in 1000 parts.		Chloride of Sodium, in 1000 parts.		Phosphate of Lime, in 1000 parts.	
SECRETIONS AND EXCRETIONS.					
Saliva	995	Mucus	6·	Gastric juice	·4
Perspiration	986	Bile	3·5		
Gastric juice	975	Urine	3·		
Urine	936	Saliva	1·5		
Pancreatic juice	900	Milk	1·		
Milk	887				
Bile	880				
FLUID PARTS.					
Lymph	960	Vitreous humor	14·	Blood	·3
Synovial Fluid	805	Aqueous ditto	11·		
Blood	795	Blood	4·5		
SOLID PARTS.					
Brain	789	Bones	2·5	Enamel of teeth	885·
Ligaments	768	Muscles	2·	Dentine of do.	643·
Muscles	750			Bones	550·
Cartilages	550			Cartilages	40·
Bones	130			Muscles	2·5
Teeth	100				
Epidermis	37				

The ultimate Chemical Constituents of the Body.

The proximate chemical constituents of the body just described, whether inorganic or organic, are themselves, with the exception of the oxygen and nitrogen in the blood, not simple bodies, but compound substances formed by the union of other elementary bodies, which are therefore the

ultimate chemical constituents of the body. For full details on this subject we must refer to *Treatises on Chemistry*: it will suffice here to state briefly, the chemical composition of the proximate constituents of the body.

As to the *inorganic* proximate constituents, their composition is comparatively simple; for they are usually made up of *two* elementary bodies, that is, they are *binary* compounds, such as water and salt, or else they appear to be formed by the union of two or more such binary compounds into one substance, as the carbonate of soda, or phosphate of lime.

If the oxygen and the nitrogen, which seem to exist free in the blood and other fluids, be really only dissolved in them, they afford examples of a simple element entering as such into the composition of the body; but it is possible that these gases are in some unknown though loose state of chemical combination in those fluids.

The carbonic acid gas is, however, a binary compound, consisting of one atom of carbon and two atoms of oxygen (CO_2, carbonic acid). Again, the water is composed of two atoms of hydrogen and one atom of oxygen, chemically combined as an oxide of hydrogen (H_2O, hydric oxide). The chloride of sodium (common salt) consists of one atom of chlorine united with one atom of sodium ($NaCl$, sodic chloride); chloride of potassium, of chlorine and potassium (KCl, potassic chloride); fluoride of calcium (fluorspar) consists of two atoms of fluorine and one of calcium (CaF_2, calcic fluoride). The alkalis, soda and potash, and the earths, lime and magnesia, are the oxides of the metals sodium, potassium, calcium, and magnesium, that is, are compounds each of one atom of oxygen with one or two atoms of those metals respectively (Na_2O, K_2O, CaO, and MgO, sodic, potassic, calcic and magnesic oxides). All the preceding bodies are binary compounds; but as examples of substances in the body, which appear to be formed by the union of two such binary compounds, we may mention the phosphates, sulphates, and carbonates of soda, potash, lime, and magnesia (otherwise named, the sodic, potassic, calcic, and magnesic phosphates, sulphates, and carbonates), which may be regarded as compounds of phosphoric, sulphuric, and carbonic acids with the above-mentioned alkalis and earths,—carbonic acid being itself composed, as already stated, of one atom of carbon and two atoms of oxygen (CO_2); sulphuric acid, of one atom of the well known substance sulphur, and three atoms of oxygen (SO_3); and phosphoric acid

of two atoms of phosphorus and five atoms of oxygen (P_2O_5). The trace of silica or flint, found in the body, is an oxide of the metal silicon (SiO_2, silicic acid). The small but essential quantity of the metal iron (Fe) exists also in some combined state; and the minute traces of the metals manganese (Mn) and copper (Cu), and of alumina, the basis of clay, which is an oxide of the metal aluminium (Al_2O_3), are perhaps accidental.

But the *organic* proximate constituents of the body have a much more complex chemical composition, though they too are resolvable by spontaneous decomposition, by chemical reactions, or by the destructive action of fire, into a few ultimate elements, which then revert to the inorganic state. The simplest of these organic constituents are *ternary* compounds, that is, they are formed by the combination of three chemical elementary substances; whilst others are *quaternary*, or even *quinary* compounds.

		Carbon.	Hydrogen.	Oxygen.
100 parts,	Stearic Acid ($C_{18}H_{36}O_2$) . . =	76·	12·7	11·3
,,	Oleic Acid ($C_{18}H_{34}O_2$) . . =	76·6	12·	11·4
,,	Margaric Acid ($C_{17}H_{34}O_2$) . =	75·5	12·6	11·9
,,	Palmitic Acid ($C_{16}H_{32}O_2$) . =	75·	12·5	12·5
,,	Glycerin ($C_3H_8O_3$) . . . . . =	39·1	8·7	52·2
,,	Cholesterin ($C_{26}H_{44}O$) . . . =	83·8	11·9	4·3
,,	Caproic Acid ($C_6H_{12}O_2$) . . =	62·1	10·3	27·6
,,	Butyric Acid ($C_4H_8O_2$) . . =	54·6	9·1	36·3
,,	Glycogen or Animal Starch ($C_6H_{10}O_5$) . . . . =	44·4	6·2	49·4
,,	Lactin, or Sugar of Milk ($C_{12}H_{22}O_{11}$) . . . . =	42·1	6·5	51·4
,,	Glucose Dextrose, or Grape Sugar ($C_6H_{12}O_6$) . . . . =	40·	6·7	53·3
,,	Lactic acid ($C_3H_6O_3$) . . . . =	40·	6·7	53·3
,,	Acetic acid ($C_2H_4O_2$) . . . =	40·	6·7	53·3
,,	Formic acid ($C_2H_2O_3$) . . . =	32·4	2·7	64·9
,,	Oxalic acid, or Hydric Oxalate ($C_2H_2O_4$) . . . . =	26·7	2·2	71·1

Thus, the non-azotised substances, fat, sugar, and the animal organic acids, are ternary compounds, each consisting of certain quantities of carbon, hydrogen, and oxygen, combined in definite proportions. The *percentage* composition of some of these substances is stated above. The small figures attached to the letters between the brackets, show the numbers of so-

called atoms of each element, which are supposed to enter into combination to form a particular substance; in other words, they show the theoretical *atomic* composition of that substance. But the percentage composition, representing in round numbers the quantities by weight of each element in 100 parts of the substance, is also of some interest.

The great characteristic of the fats, is that they are very rich in carbon and hydrogen, in proportion to their oxygen; they are known as solid *hydrocarbons.* In the sugars the number of atoms of carbon is balanced, as it were, by as much hydrogen and oxygen as would form the same number of atoms of water; hence they are frequently named *carbohydrates*, or *carbhydrates.*

The azotised substances of the body have a still more complex chemical constitution. Even the simplest of them are *quaternary* compounds, containing, besides a large amount of nitrogen or azote, certain proportions of carbon, hydrogen, and oxygen. Some of them are even quinary compounds, containing, in addition, either sulphur, iron, or phosphorus, in some yet unknown state of combination. The percentage composition of these azotised substances, as given in the next page, has been more or less accurately determined; but the atomic constitution of a few of them only, as indicated by the letters and numbers placed between brackets, is well agreed upon. Except keratin, they are all remarkably prone to putrefaction or spontaneous decomposition.

Of the azotised substances of the body, it is found, as is shown in the following table, that albumen, fibrin, and casein have almost exactly the same chemical composition. Each of them, moreover, has a minute quantity of phosphate of lime associated with it. By boiling, and so dissolving, either of these substances in a solution of caustic potash, its sulphur is removed from it; and when the animal substance is reprecipitated in a solid form by acetic acid, its composition is altered only by the loss of sulphur. This desulphurised substance,—the same in character whether obtained from albumen, fibrin, or casein,—was supposed by Mülder to be the true basis of each of these three substances, which differed only, according to this view, in the relative quantities of sulphur which they contained. This common hypothetical base was accordingly named by him *protein* (from πρῶτος, prōtos, first); and the albumen, fibrin, and casein were regarded as *compounds of protein* with sulphur, and were designated *proteinaceous substances.*

	Carb.	Hydr.	Nitr.	Oxyg.	Sulph.
100 parts Albumen . . . =	53·8	7·	15·5	22·5	1·2
,, Fibrin . . . . =	52·7	7·	15·8	23·4	1·1
,, Casein . . . . =	53·8	7·	15·8	22·4	1·
,, Gelatin . . . . =	50·3	7·2	18·	24·5	
,, Chondrin . . . =	49·3	6·6	14·4	29·3	·4
,, Keratin (hair) . =	51·	6·5	17·	25·	·5
,, Hæmatin (blood) =	65·5	5·4	10·4	11·8	6·9 (iron.)
,, Black pigment (eye) . . . =	57·5	5·9	13·7	22·9	
,, Green pigment (bile) . . . =	60·2	5·8	8·5	25·9	
,, Cerebric acid (brain) . . =	66·7	10·6	2·3	19·5	·9 (phos.)
,, Cholic Acid ($C_{26}H_{43}NO_6$) =	67·1	9·2	3·	20·7	
,, Tauro-cholic acid ($C_{26}H_{45}NO_7S$ =	60·6	8·7	2·7	21·8	6·2
,, Cholalic Acid ($C_{24}H_{40}O_5$) =	70·6	9·8	—	19·6	
,, Glycocoll ($C_2H_5NO_2$) =	32·	6·6	18·7	42·7	
,, Taurin ($C_2H_7NO_3S$) =	19·2	5·6	11·2	38·4	25·6
,, Creatin ($C_4H_9N_3O_2$) =	36·7	6·9	32·	24·4	
,, Creatinin ($C_4H_7N_3O$) =	42·5	6·2	37·2	14·1	
,, Sarcin ($C_5H_4N_4O$) =	44·1	3·	41·1	11·8	
,, Guanin ($C_5H_5N_5O$) =	39·8	3·3	46·3	10·6	
,, Xanthin ($C_5H_4N_4O_2$) =	39·4	2·7	36·9	21·	
,, Hippuric Acid ($C_9H_9NO_3$) =	60·3	5·	7·8	26·9	
,, Uric acid ($C_5H_4N_4O_3$) =	35·7	2·4	33·3	28·6	
,, Urea (CH_4N_2O) =	20·	6·6	46·7	26·7	

Protein, however, is an artificial product, the result o a very violent chemical action; and it cannot be admitte as an actual constituent of the body. On this and othe grounds, the protein-theory is not now generally accepted and it is considered better to regard albumen, globulin, syn

tonin, fibrin, and casein, as closely allied bodies, of which albumen is the type, so that they may be called *albuminous* or, better, *albuminoid* substances.

As to the other azotised bodies, in the first place, gelatin seems to be a modification of, or derived product from, albumen,—the sulphur being gone, the carbon diminished, and the nitrogen and oxygen increased. Chondrin has a little sulphur still retained in it, and so has keratin. The colouring matters of the blood, the eyeball and the bile, have also the appearance of being derived from albumen,—the carbon being increased, the hydrogen and nitrogen diminished, and, in the case of the hæmatin, an extraordinary addition appearing in the shape of seven per cent. of iron in some unknown state of combination. Cerebric acid is regarded as a slightly azotised fatty substance, which also contains phosphorus: cholic acid is also fatty; both, therefore, contain much carbon and hydrogen. Another fatty acid in the bile (the tauro-cholic) contains in addition a little sulphur. The extractive matters creatin and creatinin, sarcin, xanthin, and others, are mainly distinguished by the large amount of nitrogen they contain. This is also the case with urea and uric acid, both which excretory substances, however, are more highly oxidised, or contain proportionally more oxygen than the preceding substances.

The non-azotised bodies, such as simple fat and sugar, yield, on being decomposed or burnt, carbonic acid (CO_2), and water (H_2O) only, the additional quantities of oxygen required being derived from the atmosphere. By natural decomposition, as already stated, the azotised organic matters yield ammonia (NH_3), which consists of one atom of nitrogen and three atoms of hydrogen: those which contain sulphur (especially albumen), also yield sulphuretted hydrogen gas (H_2S), which is a compound of two atoms of hydrogen, and one atom of sulphur. By destructive heat, these substances yield, besides ammonia, water, and carbonic acid, sulphuric acid (SO_3). Any saline or earthy matter, associated in the tissues with either the azotised or non-azotised substances, is left as *ashes* after the burning.

Finally, then, it appears that the ultimate chemical elements entering into the composition of the body, are those which are indicated in the following table, to which, however, must be added a trace of manganese (probably associated with the iron), and sometimes traces of aluminium, copper, and lead,

probably accidental. The percentage proportions of these ultimate elements have been said to be as follow:—

Gases.	Oxygen	72·
	Hydrogen	9·1
	Nitrogen	2·5
	Chlorine	·085
	Fluorine	·08
Solids.	Carbon	13·5
	Phosphorus	1·15
	Calcium	1·3
	Sulphur	·1476
	Sodium	·1
	Potassium	·026
	Iron	·01
	Magnesium	·0012
	Silicon	·0002
		100·

The entire body, that is, the body with its natural moisture, is composed, therefore, of about eighty-four parts of gaseous chemical elements to sixteen parts of solid elements.

The greater part of the oxygen and hydrogen exists in the state of water, but the dried residue still contains some gaseous as well as solid elements. It will be seen that, setting aside the components of the water, carbon is the most abundant element in the dried tissues, then oxygen, next nitrogen, then hydrogen, and afterwards the other elements as placed in the table.

We have now traced the structure and composition of the lifeless human body; and we find that, at last, in the inevitable decomposition of its various complicated organs, whilst its hydrogen and nitrogen, with part of its oxygen and carbon, are restored to the inorganic world in the shape of *water*, *carbonic acid*, and *ammonia*, the rest of its carbon and oxygen, its chlorine and fluorine, its phosphorus and sulphur, and its metallic bases, calcium, sodium, potassium, magnesium, and iron, with its trace of silicon and manganese, revert to the condition of inorganic *salts* and *earths*, viz. to carbonates, sulphates, and phosphates, chlorides, and fluorides of the above-named saline and earthy bases. Its materials thus literally return to their inorganic state.

In sea-fishes, and in the lower marine animals, iodine and bromine probably are present. Iodine exists in cod's liver oil, and also in marine sponges.

PHYSIOLOGY;

OR

THE LIVING BODY.

GENERAL PHYSIOLOGY.

VITAL PROPERTIES OF THE TISSUES.

THE animal tissues, the microscopical structure, chemical composition, and physical properties of which have now been described, possess and manifest, *during life*, certain further and peculiar properties, altogether different from those exhibited by inorganic substances, at once distinguishing them from such bodies, and enabling them to perform certain important uses in the living animal body. Hence these properties have been named *vital properties*. Of these vital properties, two are special, *i. e.* are confined each to one elementary animal tissue or substance respectively; whilst a third vital property is general, *i. e.* is manifested by all the living tissues. The two former properties are *contractility* and *sensibility*; whilst the latter is known under several names, of which we prefer, as a general term, that of the *formative* or *organising* property.

Vital *contractility* is the power possessed by certain tissues of contracting, or shortening themselves, in one direction. It is especially manifested by the fibres of muscular tissue, and is most probably the source of all intrinsic motion in the living body; for it is possibly even the cause of ciliary motion, and of all the movements in animal protoplasm. It is sometimes named *irritability*, and, more definitely, *muscular irritability*: by Haller it was distinguished as the *vis insita*, or *vis musculosa*.

Sensibility is the special property of the nervous tissues. If

taken to represent all the vital properties of nervous substance, in which general sense it is here understood, sensibility is a more complex endowment than the contractility of the muscular tissue. It might be spoken of as the nervous irritability, but a common and more appropriate term for it is the '*excitability*' of the nervous tissues. This peculiar vital property of nervous excitability is manifested both by the nerve-fibres and the nerve-cells. In the former, it appears as *simple excitability*, or the property of receiving impressions from, or being excited by, certain stimuli; whilst, in the latter, it assumes more special forms of reception and reaction, constituting true *sensibility*, to which must be added *volitional* and *excitomotory* or *reflex* power. Moreover, both forms of tissue are able not merely to receive, but also to transmit, the effects of impressions, whilst the nerve-cells especially originate internal actions. The nerve-fibres possess, in a marked degree, the power of conducting the effects of impressions, either inwards to proper receptive or reflective nervous centres, endowed with *special excitabilities*, which are then called into play, or outwards to the muscular organs, which being endowed, as we have seen, with contractility, then contract. That action of the nerve-fibres of certain nerves, which consists in conducting the effects of stimuli to the muscular tissue, and causing it to contract, was named by Haller the *vis nervosa* ; and there is reason to believe that the property, by which other nerves conduct the effects of stimuli inwards to the nervous centres, is of precisely the same nature. This power of conducting the effects of impressions, in either direction, may be named *conductility*, or, as has been suggested, *neurility*; whilst the general term excitability must include, not only this conductility, but likewise the power of receiving impressions, possessed by the nerves and nervous centres, and also the special reactions and actions of the latter, whether these be sensorial or motorial.

The general *organising* or *formative* property is that on which the *development*, *growth*, and *nutrition* or maintenance, of all the animal tissues depend. It is also a complex property, or may, at least in imagination, be supposed to consist of two associated properties. One of these is *purely assimilative*, and enables a tissue to appropriate to itself such external matter as it needs, and to convert it into its own substance, for the purposes of its increase, whilst undergoing development and growth ; or for its maintenance during those conditions

of waste and renovation, which accompany and follow the exercise or use of the tissue. This purely assimilative or nutritive property is sometimes named the *metabolic* property or *vital affinity*. The second organising property modifies or controls the direction of the assimilative property, so far as to guide its operation to the production of certain *organic forms*, both in the entire individual, and in the separate organs, parts, tissues, and ultimate structural elements of which it consists. This is the *proper* organising or *plastic* property, and has been also named the *metamorphic* property. The metabolic or assimilative process is evidently a chemical process of a higher character than ordinary chemical processes; or, as it may be termed, a *vito-chemical* process; but the metamorphic or plastic property is purely and absolutely a *vital* process.

Of the three general vital properties just described, the last, or organising, property is common to plants and animals. An imperfect form of contractility occurs in a few parts of certain plants; but sensibility, or nervous excitability, is quite peculiar to animals.

These vital properties of the animal tissues seem to be, as it were, dormant in the living organism, whether it be a germ, embryo, or adult, unless they are called forth by the action of various agents, named *stimuli*. Such stimuli, from their operation being peculiar and essential to living bodies, are sometimes entitled 'vital' stimuli; but that term is more appropriately limited to such stimuli as actually originate in living organisms. Speaking generally, the stimuli to life are some external, and some internal. The *external* stimuli are either mechanical, physical, or chemical, such as pressure, friction, pricking, or cutting, heat or cold, electricity, light, and various chemical agents. Such stimuli, with the exception of light, if applied to a contractile or muscular tissue, cause it to contract; if applied to the nervous tissues, they rouse their excitability, bring into operation the conductility of the nerve-fibres, and, through them, excite the special sensibilities of different nerve-cells, or, indirectly, induce muscular contractility. In the former case, one result only is produced, whatever be the nature of the stimulus, viz. contraction or motion; in the latter case, the effects differ according to the nature of the external stimulus, or the character of the nervous excitability of particular nerves or nervous centres, *i. e.* to their susceptibility to react in a peculiar manner in relation to those stimuli. Thus pressure produces the sensation of touch;

changes of temperature the sensations of heat and cold; rapid mechanical vibrations, hearing; chemical actions excite taste and smell, and luminous vibrations produce sight. The *internal* stimuli are partly of the same nature as the external stimuli, as, *e. g.* the stimulus of food, which is partly mechanical, and partly chemical, and which may produce both motion in contractile tissues, and sensation in sensitive tissues. Of the same nature, is the internal chemical stimulus of the blood, chiefly due to the oxygen which it absorbs from the air; and, lastly, to this category, also, belongs the physical stimulus of the internal animal heat proper to the individual. The last-named stimuli might be called *vito-physical* and *vito-chemical.* There are other internal stimuli which may more properly be named *vital*, for they are neither mechanical, physical, nor chemical. These are the purely *mental* stimuli, which arise from consciousness and perception, and are either ideational, emotional, or volitional. These, however, also originate, so far as the body is concerned, in peculiar states, conditions, or affections of the nervous centres, and in them only; and, as we shall hereafter see, their exercise is always associated with chemical and electrical changes in the nervous molecules, and therefore they present likewise a vito-physical and vito-chemical aspect. The stimuli which act on the body from without, have been characterised as objective, and those which act from within, as subjective stimuli; but, as we shall explain in the chapter on Sensation, in speaking of the so-called objective and subjective sensations, there is a certain confusion in the use of these too much hackneyed and sciolistic phrases.

The external and internal stimuli, mechanical, physical, chemical, and vito-physical, vito-chemical, or vital, also operate on, and excite, the assimilative and plastic property of the tissues. Thus, without external heat, no seed or germ is developed, heat being the so-called 'efficient cause,' or 'motive power,' of all germination, development, growth, and nutrition; and certain ranges of temperature are subsequently essential to the excitement and maintenance of all the nutritive processes. Food, water, oxygen, and other chemical agents, are essential to the manifestation of plastic power. Light also exercises a stimulating influence upon this property; and, when the organism is once formed and complete, the internal stimulus of the blood, and that of the animal heat, also excite, and support, the formative and assimilative processes. Lastly, the purely nervous and mental stimuli, originating in the

nervous centres, likewise modify the formative and assimilative processes.

The *uses* of the three so-called vital properties of the animal tissues, may be thus briefly summed up. The use of contractility is to produce all the varieties of independent motion proper to certain parts of the living frame. The use of the excitability and conductility of the nervous tissue, is shown in the control of the movements of the body, both involuntary and voluntary, and in the various forms of sensation, and their consequences, such as emotion, thought, and will. Lastly, the office of the organising power, *i. e.* of the conjoined assimilative and plastic powers, is the formation, development, and growth, of all the individual tissues, parts, and organs of the body, and their maintenance in an active living condition.

In that condition, there occurs a ceaseless internal motion and change of material, involving the constant removal of old, or used and disorganised, matter, and the absorption and conversion, the assimilation and organisation of new matter, which are the great characteristics of a *living* body. The cessation of these changes constitutes *death.*

Indeed, it is this active condition of all the parts of the body, manifested through the exercise of the various vito-physical, vito-chemical, and vital properties, called into play by external and internal stimuli, which yields a total result known as '*vital action*,' or '*life*.' The life of an individual animal is the sum of its various actions, the aggregate of its vital phenomena. 'Life is organisation in action' (Béclard). Sometimes, however, the term life has been understood to signify 'the mode of action' of living bodies. Again, it is also frequently employed to indicate a special agent, principle, or entity, which is considered to be the source, or cause, of all the vital properties and actions; but this use of the word is, perhaps, better avoided. The term 'vitality' has a somewhat similar signification; but it might rather be restricted to the power or capacity of living. The expression '*vital force*' indicates a still further step made by our minds in the endeavour to define the causation of vital phenomena. The use of the term 'force,' in this sense, is hardly to be avoided in physiological discussions any more than that of the 'force' of gravitation in physical explanations; but it is, unfortunately, employed in totally dissimilar senses. A vital 'force' is as unknown to us as the force which causes gravitation or attraction; and we can only infer or assume its existence, as the cause of certain

properties in living things: we cannot know it. Besides this, we use the term 'force' very differently, when we speak of the vital force of the whole system, in relation to health or disease, or, separately, of the muscular, nervous, and plastic forces, or of the force of the arm, the heart, or the thorax, or of the secreting force of a gland, or of the solvent or digestive force of the gastric juice. We shall hereafter see reason to regard most of the so-called forces, thus assumed to operate in the body, as modifications of that common force which, in the inorganic world, is supposed to act in various modes, sometimes by attraction—as in cohesion and gravitation—the latter being often a cause of visible motion; sometimes as an invisible motion, causing heat; at other times as light, or electricity, or chemical affinity; all which phenomena are supposed to be due to correlated manifestations of one and the same universal force pervading all matter. In living animal bodies, we need no longer assume the presence of so many distinct and peculiar forces as were formerly admitted. As we have seen, all the vital actions of animals may be referred to three primary properties—contractility, nervous excitability, and the organising property. But, even for the explanation of these, we do not require to assume the existence of three corresponding and purely vital forces, entirely unrelated to the supposed common force of nature; for the contractility of muscle, the simple excitability and conductility of the nerve-substance, and the assimilative or metabolic affinity of the tissues, though truly named vital properties, as being only exhibited by living bodies, may all depend on, or rather may be merely modifications or special manifestations, within the living organism, of the common force of nature, acting either mechanically, osmotically, electrically, or chemically. Even the higher excitability of the nervous cells, manifested in actual sensation and its mental consequences, does not, as already pointed out, escape association with such corporeal changes as may well be regarded as dependent on vito-physical and vito-chemical modes of action of that common force. But there remains a mystery in this manifestation of *feeling* and *consciousness* in connection with matter, even when contemplated in the case of animals, which no physical hypothesis has yet cleared up. Moreover, the vital phenomena dependent on the higher organizing or metamorphic property, cannot at present be so explained; nor is it easy to conceive the possibility of so explaining them, by reference merely to mutations of the

universal physical force, which undoubtedly subserves, and is essential to, their manifestation.

The formation of a fluid or solid mass of albuminoid protoplasm, *may* be conceived to be due to a vito-chemical process, and its maintenance to vito-chemical changes; but the *shaping* of this to an organic form, whether a nucleus, a naked nucleated cell or gymnoplast, or a perfect cell with envelope or cystoplast, or the multiplication, modification, and adhesion of these in definite order, manner, and connexion, to form a complex animal or vegetable, implies the presence of some further controlling power. There would seem, indeed, to be some special force in animals and plants, by which the tissues, parts, and organs are evolved in determinate shape, size, and position, and are definitely endowed with their ordinary properties; and by which, moreover, entire organisms are developed in apparently endless variation, according to the distinctions of kingdoms, classes, orders, genera, species, race, sex, and individuality. These remarkable phenomena are accordingly said to imply the presence of a guiding, controlling, and dictating force, modified in innumerable ways by external and internal conditions, transmissible from generation to generation, and certainly distinct from, though co-operating with, the common physical force of nature. This is truly a '*vital*' force,—a force properly called 'organic,'—on which the very existence of both animal and vegetable organisms depends. It is this force, also known as the 'germ force,' which develops and maintains the body and all its parts, with their respective vito-physical, vito-chemical, and other so-called vital properties, and so imparts to them even their very highest endowments.

GENERAL VIEW OF THE ANIMAL FUNCTIONS.

The life of man, and of the higher animals, consists ultimately, as already said, in the manifestation of the various properties of the structural elements of the different tissues and fluids; but, in its more obvious effects, it is manifested in certain special acts, which are known as *functions*, performed by the instrumentality of the parts named *organs*. Life, as we have seen, is organisation in action. These functions are the endowments of the organs, just as the vital properties are the endowments of the tissues; and, as most organs are constructed of many tissues, the functions of such parts are

necessarily more complex processes than the fundamental actions of the tissues.

The functions of animals are divided into two principal groups, named respectively, the *animal* and the *vegetative* functions, the former being essentially limited to animal organisms, the latter being common to both animals and vegetables.

In contemplating the phenomena presented to our notice by one of the higher animals, *e. g.* by the dog, or rabbit, the dissection of which latter animal has been previously described (page 34), the most obvious fact is their power of moving from place to place, and of performing various other actions, prehensile, offensive, defensive, and so on. These several movements are ascribed to the common function of *motion*, including the acts of locomotion, prehension, and others, performed by means of the so-called *passive organs* of motion, the *bones* and *joints*, and by the *active organs* of motion, viz. the *muscles* and their *dependencies*.

But the movements of the dog are neither desultory nor irregular, but are evidently directed to certain ends and objects desired by, or useful to, it. For this purpose, the animal must *feel*, using that term in its widest sense; it must also be able to *perceive*, and, to a certain extent, to *reason* upon the results of certain external influences, to *desire* to obtain this or to avoid that; and it must possess the power of *will*, issuing in the *voluntary control* over the muscles, the immediately active organs of motion. Besides this, it is endowed with an *involuntary regulating power* over certain movements, which tend to the preservation of its various organs from injury, or aid in the performance of certain important vegetative functions, such as deglutition and respiration. In these various states and acts, the animal exercises the functions of *sensation*, the *psychical functions*, and those of the *regulation* of the *muscular movements*, all of which are accomplished through the agency of the nervous apparatus, consisting of the *brain* and *spinal cord*, of certain *ganglia*, and of the numerous connected cords formed by the *nerves*. In the exercise of the various kinds of sensation, the animal feels, tastes, smells, hears, and sees, by means of the vibrissæ, tongue, nose, ears, and eyes, *organs* of *special sense*, furnished with appendages for their protection and more efficient use, and destined to receive impressions made by various external stimuli, the effects of which are transmitted by special nerves

to the great organ of sensation, the brain. In this organ, also, not only consciousness of the sensations, but all other psychical phenomena, have their corporeal seat; such as perception of the outward causes of the sensations, ideas, emotions, desires, reasoning processes, and will, the stimuli or mandates of all which latter proceed from the brain to the muscles, destined to perform the necessary ideational, emotional, or voluntary acts. In other cases, stimuli produce impressions on the nerves, which are conveyed to the spinal cord, or to its extension upwards into the head, named the 'medulla oblongata,' and do not induce sensation, but are *reflected* outwards involuntarily along other nerves to particular muscles, which then contract and perform the necessary movements. There exist accordingly, in the animal organism, *sensory nerves* and *sensorial nervous centres*, *motor nerves* and *motorial nervous centres*; and there are also found nervous centres concerned in the reflected or *reflex* motor actions of the body.

These mixed motor, sensory, and psychical functions, which constitute the so-called proper *animal* functions, cannot be performed continuously without cessation. The animal sooner or later becomes exhausted in regard to them; the brain becomes weary and the muscles fatigued. Rest is indispensable. These functions are for a time suspended, and the condition known as sleep occurs, which, when perfect, is accompanied by the temporary suspension of all these animal functions — motor, sensory, and psychical. But sleep is insufficient of itself permanently to restore animal activity. In the exercise of the muscular and nervous systems, these organs undergo a destruction or waste of their component molecules. During every interval of rest, as well as during sleep, they are renovated by materials derived from the common nutrient circulating fluid, the blood. But the blood itself, in thus contributing to restore the wasted nervous and muscular organs, itself becomes impoverished. Under these circumstances, it may, for a time, draw material from one part of the body to sustain, as long as it can, another part,—the more passive organs of the frame yielding nutriment to those more actively endowed. But the waste still goes on in proportion as action is renewed; fatigue again ensues; rest and sleep are once more indispensable. The animal day by day would emaciate, get weaker, and ultimately die of inanition. To prevent this, new material must be added to the blood from the outer world. This material consists of food, drink, and

air; and to impel the animal to seek them, the *special feelings of hunger and thirst* arise within it. Besides this, during the waste of the active tissues in the proper animal functions, the products of the decomposition of the wasted substance of the muscular and nervous systems, and of their dependencies, are drawn into the current of the circulation, and render the blood more or less impure. Its impurities, so derived, must be thrown off; otherwise life would be extinguished, not by inanition, but by an act of self-poisoning, either slow or rapid, according to the nature and quantity of the impurity so retained in the circulating fluid.

Hence to maintain the balance between the necessary waste and renovation of the body, to preserve the purity of the blood and the integrity of the animal organs, and so render possible the due exercise of the proper animal functions, certain other, and most complex, functions require accordingly to be regularly performed. These, which form one subdivision of the group of *vegetative* functions, are named the *nutritive functions.*

The animal, constrained to seek for food, seizes it by prehensile movements, and introduces it into the interior of its body, exercising thus the function of *prehension* of food. Such food is, however, unfitted, without due preparation, for actual entrance into the substance or tissues of the animal, and is therefore subjected to certain special processes, included in the general function of *digestion*, performed by the *alimentary canal* and *its appendages.* First, the food, at least in the higher animals and in man, requires to be bruised or comminuted by the process of *mastication* performed by the *teeth, jaws*, and *muscles*, concerned in this act, aided by the *tongue* and *cheeks.* During this reduction of the food, another process is necessary, especially when the food is dry; and that is, its admixture with a large quantity of fluid matter, named the *saliva*, which is formed by the salivary glands, and by aid of which the mass of food is rendered soft enough to be swallowed, while certain of its ingredients are subjected even to chemical change. This constitutes the process of *insalivation.* The *swallowing* of the food, which is named the act of *deglutition*, is performed by aid of the *tongue*, the part called the *fauces*, the *pharynx* or back of the throat, and the *œsophagus* or *gullet*. From the lower end of the gullet, the masticated and insalivated food is propelled into the *stomach*, where it undergoes *gastric digestion* or *digestion proper*, under the agency of the

gastric juice, which acts chemically on certain portions of the food, and aids in its solution, performing thus the process of *chymification.* By certain movements of the stomach, the softened portion of the food, now named the *chyme*, is urged onwards into the *small intestine*, at the upper part of which it becomes admixed with the *bile* formed by the *liver*, and with the *pancreatic juice* yielded by the *pancreas.* These fluids continue the chemical processes of change and solution already commenced. It also is blended with the so-called *intestinal juice.* After this, the pulpy mixture is fitted for the next great vegetative function, characteristic of all organised bodies, viz. the function of *absorption*, by means of which, the fluid and dissolved parts of the food and drink at length enter into the substance of the living animal, and ultimately gain access to the blood. This absorptive process is accomplished, partly by means of the *bloodvessels* of the stomach and small intestine, and partly by the agency of the special *absorbent vessels* known as the *lacteals.* These, after passing through the *absorbent glands*, which elaborate the fluid conveyed through them, at last end in the chief absorbent trunk, named the *thoracic duct*, which then pours its contents into the great veins at the root of the neck. The part of the dissolved nutrient matters which enters the absorbents of the small intestine consists of an opaque white *fluid*, called the *chyle*; and the formation of this fluid is termed the process of *chylification.* In this way, partly directly and partly indirectly, the nutrient substances of the food, dissolved and modified by the digestive processes, enter the bloodvessels, and renew the materials of the blood. The unabsorbed residue of the food and digestive juices, gradually passes from the small into the *large intestine*, in which, by a sort of *secondary*, or *continued digestive* process, any remaining nutritive matter is almost entirely taken up from it. The final residue, including certain products of decomposition, and other substances thrown off from the system by the liver and the lining membrane of the intestines, forms the solid excreta or egesta, which are removed from the body by the process of *defæcation.*

The blood, thus nourished by what is termed the *primary process of assimilation*, is conveyed through every part of the body, by means of the *heart*, the arteries, the capillaries, and the veins. It is propelled from the heart through the arteries, passes from them into the capillaries, and returns thence to the heart through the veins. Thus the function of *circulation* is

performed, the parts just named constituting its organs. In the higher animals, and, in man, the circulation is double, or consists of two circular currents, each proceeding from the heart, and returning to that organ again; one, passing through the body, is named the *systemic*, the other, through the lungs, the *pulmonary circulation*. In the former, a pure or arterial blood proceeds from the heart, whilst an impure or venous blood returns to it; in the latter, the blood issuing from the heart is venous or impure, whilst it returns arterialised or pure.

We have now arrived at the point at which the waste of the organs concerned in the animal functions of sensation, mental action, and motion, may be repaired by the great and common function of *nutrition proper*, *nutritive secretion*, or *secondary assimilation*. To accomplish this, new materials in a dissolved state, derived from the blood, percolate through the fine walls of the capillary vessels, and constitute what is called the *nutritive plasma*. From this common transparent colourless fluid plasma, which moistens every tissue of the body, the elementary tissues of each organ appropriate, by their assimilative property, such materials as are needed for their renovation, or the restoration of their wasted molecules; and, under the influence of their plastic property, deposit the new material, molecule by molecule, in the place of the disintegrated or wasted substance, so as to preserve, unchanged, the characteristic elementary structure of the tissue, and the general form of the organ so nourished. The residual plasma passes, it is supposed, together with the products of the wasted tissue, back into the blood again, in part, directly, through the walls of the capillaries and finest veins, but also, and chiefly, through the general *absorbent vessels*, which resemble the lacteals already mentioned, but which are named *lymphatics*, because they here carry a clear fluid or *lymph*. Should accident or disease still further impair the integrity of an organ by bruising, cutting, or by inflammatory processes, the nutritive function is exercised, in a special manner, for the *reparation* of the injured part, and sometimes even for the restoration or *reproduction* of lost parts. Nutrition includes, therefore, the processes or functions of reparation and local reproduction. Lastly, parts which are destined to be removed, such as the fangs of the milk teeth, and the materials of the growing bones; or morbid deposits, such as blood which has escaped from the vessels into the tissues; and inflammatory products,—are likewise absorbed back into the blood, by the act of *nutritive*

absorption, which is performed jointly by the capillaries and the lymphatics.

But, besides all this, there is included in the nutritive function, the conveyance of a so-called *stimulating* substance to those two remarkable tissues of the animal body, the muscular and the nervous tissues, both of which require, for the performance of their proper functions, not only new material to replace that which is destroyed or disintegrated by use, but likewise the presence of arterial blood, for the maintenance of their peculiar vital endowments: such blood operates chiefly by virtue of the large quantity of oxygen which it contains. In supplying the requisite materials for the nutrition and stimulation of the tissues, all of which have their characteristic chemical composition, in receiving back the residual nutrient substance, and in furnishing the materials for another important nutritive function, named *secretion*, to be presently described, the blood itself becomes not only exhausted as regards the quantity of its ingredients, but necessarily modified as regards their quality; and hence certain special elaborative processes are continually going on, for the purpose of securing its own nutrition; these constitute the function of *sanguification*. This is accomplished partly by the absorption of new matter entering through the lacteals and the absorbent glands, already mentioned, and also it is believed by the agency of certain organs named vascular glands or blood glands, such as the *spleen*, the *supra-renal bodies*, the *thyroid body*, and the *thymus gland*, and the so-called *Peyer's glands* and *solitary glands* of the intestinal canal, all of which appear to assist in the elaboration of special materials for the blood.

We have seen that in order to render the nutrient substances contained in the food soluble, and fitted for absorption, certain animal fluids or juices are employed in the process of digestion, such as saliva, gastric juice, bile, pancreatic fluid, and the intestinal juice. These special fluids require each a special organ in the body for its preparation, named a *gland*. Moreover they are prepared within these glands, from the fluid plasma of the blood poured out through the coats of the capillaries. The general process by which they are thus separated from the blood, is known as *secretion*, and the glands are called *secreting glands*. The process of secretion is closely allied to that of nutrition; in the former, the fluid material elaborated from the blood, escapes on to the external or internal surfaces of the body; whilst in the latter it is retained within

the body in the more solid form of tissue. Besides those just mentioned as associated with the alimentary canal, other glands, such as the *lachrymal* and *mammary* glands, exist, the secretions of which fulfil special offices in the economy. In addition to the continued alteration of the blood produced by its subservience to so great a variety of nutritive processes, by the loss of stimulating material conveyed to the muscular and nervous tissues, by the varied process of secretion, and by the operations connected with nutritive absorption and sanguification, the blood, as we have seen, is made the vehicle for the reception of the waste material of the disintegrated tissues, which, dissolved in the residual plasma exuded amongst their ultimate structural elements, is, at least in part, reabsorbed into the circulating current. These effete matters, if permitted to accumulate in the blood, poison it, and render it unfit for the stimulation of the nervous and muscular tissues, for the proper nutrition of the tissues generally, and for the purposes of healthy secretion. Accordingly, another functior is added to the nutritive vegetative functions of the animal economy, named *excretion*, by means of which the blood is enablec to get rid of these effete materials through the action of certair emunctory organs, named the *excreting glands*, of which th chief are the *kidneys*, the *cutaneous sweat glands*, and th *lungs*. The liver and the intestinal mucous membrane, moreover, also assist in this excretory function. By means of th urinary, cutaneous, and pulmonary excretions, and of the soli excreta from the alimentary canal, all the products of th decomposition of the tissues are regularly removed; and a these tissues are as constantly renovated from the blood, an the blood itself from the food, there exists a balance in th nutritive actions of the living economy, and a correspondenc between the daily quantity of food consumed, and the dail amount of the vito-chemical nutritive changes occurring i the body.

Of the various excretory processes, there is one, viz. the elim nation of carbonic acid from the lungs, which is distinguishe from the rest by its being associated with another proce equally essential to animal life, viz. the introduction of oxyge into the blood and tissues of the living animal. This is accon plished in *breathing*, the characteristic act of that most in portant function, *respiration*. After the reception of food in the body, all the ensuing nutritive processes which we ha described above, are hidden or concealed from observation; b

the process of breathing is one which is externally manifested. The animal under observation, indeed, is seen to breathe; the sides of its thorax expand and contract, and it alternately draws in and expels air from the interior of its frame. The air enters through the *nostrils*, and also sometimes through the *mouth*, into the *throat* or *pharynx*, and thence through the *larynx*, *windpipe* and its subdivisions into the *lungs*, and then it is again expelled from those organs through the same *air-passages.* The former act is called *inspiration*, the latter *expiration.* The air which escapes from the lungs has not the same chemical composition as when it entered them; for, within those organs, it comes into very near proximity with the blood in the capillaries of that part of the circulation named, as before mentioned, the pulmonary circulation; and there an important interchange of certain gases takes place, through the coats of the pulmonary capillaries, between the blood and the inspired air. The air receives, besides moisture, a certain quantity of *carbonic acid*, an excreted product from the impure or venous blood. Thus the lungs become important excretory organs, so important that the arrest of respiration is speedily followed by death. But more than this, the inspired air imparts to the blood a like quantity of *oxygen*, which converts the venous or impure blood, brought from the body through the systemic circulation to the heart and thence propelled through the pulmonary circulation to the lungs, into pure or arterial blood, which goes back to the heart, and is thence again propelled into the systemic vessels of the whole body. The air taken into the lungs is therefore the source of the oxygen of the arterial blood, which nourishes the whole frame, and especially stimulates the muscular and nervous tissues, and so maintains the proper animal functions. This oxygen moreover is the main agent, as it would seem, in the disintegration of those two tissues; and the chemical changes effected by its union with their molecules, are intimately associated with the exercise of their special properties of contractility and excitability—so much so, that these properties cannot be manifested without chemical change or *oxidation.* The chemical work thus performed is probably, as we shall see, truly correlated with the *motor* or *mechanical work*, i. e. with the contractile power of the muscles, and also with the more recondite *nervous action*; partly also, it is transformed into *animal electricity* in these two tissues; and lastly, the oxygen of the air, in producing these chemical changes within

the body, all more or less stages of oxidation, likewise produces, as in cases of ordinary combustion, an *elevation of temperature* in the animal frame. Respiration is therefore the functional source of *animal heat*, an important use of this function in the economy, being to produce such heat. In the warm-blooded animals, however, the oxidation of the tissues only, is insufficient to produce an amount of heat adequate to maintain the other functions of their economy, whether animal or vegetative; and hence, such animals take in their food certain additional materials, besides those used for the nutrition of the tissues—materials which merely enter the blood, and therein become oxidated or burnt, for the purpose of producing the required additional amount of heat. Unless therefore, the animal here supposed to be under observation, be supplied with fat as well as flesh, its activity is lessened, its health is impaired, and its body seriously emaciated.

The entire series of vegetative functions, which we have now examined, viz. digestion, absorption, circulation, nutrition, sanguification, secretion, excretion, and respiration, are named, as we have seen, the *nutritive vegetative functions*, because they are concerned especially in the maintenance and support of the body of the individual animal. They supply the large and constant wants of the proper animal organs of motion and sensation, but their healthy performance demands that their own organs should likewise be duly nourished. Moreover, these organs themselves contain both motor and sensory parts, i. e. muscular and nervous tissues. The former are exemplified in the muscles of mastication and deglutition, the muscular coats of the alimentary canal, the walls of the heart, the muscular tunic of the arteries and of the ducts of glands, the respiratory muscles, and the muscular fibres of the larynx and air-tubes. The latter consist of various nerves and nervous centres, especially of the so-called *sympathetic nervous cords* and ganglia, hence named the *organic nervous system*. But even the *animal nervous system*, in its various healthy and morbid states, has most important influences upon all the nutritive vegetative functions, aiding or interfering with those of digestion, nutrition, secretion, and the rest.

The nutritive vegetative functions begin, with the exception of digestion, to be manifested at the very commencement of individual life, and they continue through the whole period of existence from youth, through the adult state, to old age. But the life of the individual is limited, and to avoid th

extinction of race, which would otherwise follow such limitation, provision is made for the continuance of the species. Hence in both plants and animals, an additional vegetative function is met with, by means of which, through the evolution and development of germs, gemmules, or ova, new individuals are successively formed from previously existing parents, generation after generation. This, the last function we have to mention, is the *reproductive vegetative function*, in which are included the phenomena of *development and growth.*

The following Table will serve not only to give a general view of the different functions, but also to indicate the order in which they are hereafter described.

The Functions of Living Animals.

ANIMAL FUNCTIONS	Motion. Sensation, regulation of movement, and the higher psychical functions.
VEGETATIVE FUNCTIONS:—	
Nutritive . .	Digestion: Mastication, Insalivation, Deglutition, Digestion proper, or Chymification. Absorption; Chylification. Circulation. Nutrition and Reparation. Sanguification. Secretion. Excretion. Respiration; Production of Heat, Motion, and Electricity.
Reproductive .	Generation. Development and Growth.

RELATIONS OF MAN WITH EXTERNAL NATURE.

In the preceding pages, man's relations with both inorganic, and organic or organised, bodies, whether vegetable or animal, have been fully illustrated. With the inorganic kingdom of nature, man is related, as we have seen, both in regard to the matter which composes, and to the forces which operate within, his frame. As regards the vegetable and animal kingdoms, he is related not only materially, as implied by his dependence upon them for food, clothing, and protection, but with animals, at least, he is both socially and morally connected, as indicated by the employment of those creatures for his use, and by the ties established between himself and them in their domesticated condition.

To the physiologist, however, there are other and nearer relations of special interest, viz. *zoological* relations, as between man and animals only; *biological* relations, as between man and organised bodies generally, whether animal or vegetable; and, lastly, *physical* and *chemical* relations, as between him and the inorganic world. These last-named relations are included in those which exist between organised and unorganised bodies generally. Each of these three kinds of relation requires to be separately examined.

RELATIONS OF MAN WITH ANIMALS.

The zoological relations of man with the animals disclose points of resemblance and of difference between them, exhibited in both structural and functional peculiarities. Modern zoology is founded on what might be termed *zoological anatomy*, of which *human* and *comparative anatomy* are merely branches, inseparably connected, mutually explaining and assisting each other, and leading the mind to wider views of structure, to the laws of analogy and homology established by so-called philosophical or transcendental anatomy, and also to strictly scientific, because truly natural, systems of classification. So likewise, there is a *zoological physiology*

according to which, the modern physiologist, following the example of the anatomist in regard to structure, endeavours to trace a given function through its various degrees of complexity, down to its simplest, and therefore most essential expression. Thus it is, he follows the various sensory endowments of man and the higher animals, as exhibited in the phenomena of the special senses, downwards through the animal scale, observes them becoming fewer and simpler, and at last finds, in some lowly organised animal, common sensation alone present, and thus arrives at the simplest expression of sensibility, viz. mere nervous excitability; in other words, he traces the specialised functions of an organ gradually downwards, till it is reduced merely to the vital property of a tissue. So again, tracing downwards the function of absorption, he speedily meets with animals destitute of special lymphatic or lacteal vessels, and in which, therefore, vascular absorption and circulation are functions performed by the same set of vessels. In like manner, the function of circulation itself becomes more and more simplified, and finally disappears in animals which are destitute of vessels containing a common nutritive fluid. If he turns to digestion, he discovers some animals destitute of digestive glands, others possessing no distinct alimentary canal separate from the general cavity of their body; and lastly, others which are even destitute of a body-cavity. In the last case, nutrition is accomplished by the direct application of the surface of the animal to its food, and by the simple process of direct absorption into its substance. Viewed in this manner, the function of digestion is seen to be reduced to the phenomena of solution and absorption; whilst, together with absorption, sanguification and circulation, which are subsidiary functions, it resolves itself into one common function, viz. nutrition. This, indeed, is the simplest expression of all the nutritive functions, and is fundamentally represented by the conjoined assimilative and plastic vital property of the simplest organised tissue, or the simplest form of independent animal life. Lastly, if we trace back the secretive function, we find that a complex organ, like the liver of man and the higher animals, is, in the lower ones, represented by a cluster of follicles, by a single follicle, or by a group of nucleated cells upon the surface of a membrane; and hence we perceive that the essential character of the function of secretion, consists in a modification of the same common property of nutrition, which is named nutritive secretion; and so on of other functions.

To trace these points of comparison, both of structure and of function, between man and animals, frequent reference will have hereafter to be made to facts and details, which will be easier of comprehension, if we first take a general view of the animal kingdom. Motives of utility, and want of space, necessitate the selection and employment of one system of classification only; and preference is here given to the arrangement proposed by Professor Huxley in his *Elements of Comparative Anatomy*, which, besides containing original suggestions, incorporates the improvements of the modern German school.

Outlines of the Animal Kingdom.

The dependence of the classification of animals on their internal structure is fully illustrated in the Cuvierian system, which forms the foundation of all modern arrangements; it has, however, undergone modification, through the further application of the anatomical method, and more extended inquiries into the structure of many of the lower animals, which from want of means or of opportunity of investigation, were but imperfectly known to Cuvier. In his great contribution to comparative anatomy and zoology (*Le Règne Animal*) he divided the entire animal kingdom into four subdivisions, named *subkingdoms*. These subkingdoms were composed of nineteen primary subdivisions named *classes*, which were further broken up into seventy-seven *orders*, and these again into further groups, ultimately separated into *genera* and *species*.

Cuvierian Arrangement.

1. VERTEBRATA

Mammalia
Aves
Reptilia
Pisces

2. MOLLUSCA

Cephalopoda
Pteropoda
Gasteropoda
Acephala
Brachiopoda
Cirrhopoda

3. ARTICULATA

Insecta
Arachnida
Crustacea
Annelida

4. *RADIATA*

Echinodermata
Intestina
Acalepha
Polypi
Infusoria

The preceding table is so arranged as to shew at a glance the four Cuvierian subkingdoms and their respective classes. The Radiate subkingdom is now scattered. As regards the classes, the names printed in italics, indicate those which have been since subjected to various degrees of change, either having received additions, been broken up into distinct classes, transferred to others already existing, or even placed in entirely new subkingdoms.

The primary divisions or subkingdoms of Cuvier, are not founded on any one common principle, but each is based upon a separate mode of distinction or definition. Thus the *Vertebrate* subkingdom, including, as seen above, the classes of Mammals, Birds, Reptiles, and Fishes, has for its basis, a point of internal structure, viz. the possession of a vertebral column or back-bone, forming the fundamental part of the internal skeleton. The subkingdom *Mollusca* contains the classes Cephalopoda, illustrated by the cuttle-fishes and nautilus; Pteropoda, or sea-butterflies, marine animals, represented by the clio and others; Gasteropoda, consisting of snails, slugs, whelks, periwinkles, limpets, and other marine animals with univalved shells, as well as numerous sea-slugs and other allied shell-less species; the class Acephala, or headless molluscs, including the Testaceous bivalved oysters, mussels, cockles, scallops, and others, with the so-called simple and compound Tunicated marine animals; the Brachiopods, also bivalved marine animals; and lastly, the Cirrhopods or barnacles. The Mollusca are so named from an external general character which is common to them all, though less marked in the barnacles, viz. a soft fleshy kind of body. The *Articulate* subkingdom, comprehends Insecta, with the myriopods, or centipedes and millipedes; Arachnida, or spiders; Crustacea, including crabs, lobsters, shrimps, and many smaller crustaceans; and all the Annelida, such as worms and leeches. It is based also on a general external character, viz. the more or less jointed or divided form of the body, and limbs, where these exist. Lastly, the *Radiate* subkingdom is founded also on an external character, derived from the general radiated form of the body, or of the appendages situated around the mouth, or oral aperture, of the body-cavity: it includes the Star-fishes, the Intestinal Worms, the Medusæ or sea-nettles, the various Polyp-shaped animals, such as the sea-anemones, the gelatinous polyps resembling the little fresh-water hydra, and also the coral-forming polyps; and finally the class of Infusorial animalcules, including the Rotiferous or wheel animalcules.

The definitions of the classes were for the most part, and, indeed, always so far as his knowledge extended, founded by Cuvier, on anatomical characters. Imperfect knowledge led him, however, to an imperfect separation or grouping of these in certain instances. The results of modern investigations are embodied in the following table of the subkingdoms and classes, which exhibits the classification adopted by Huxley, with the single exception of placing the Infusoria as a class amongst the Protozoa, instead of ranking them as a more important independent group. The subkingdoms, seven in number, and the classes, twenty-six in number, are arranged on a similar plan to that already adopted in regard to the Cuvierian system, so that the two may be readily compared.

Modern Arrangement.

1. VERTEBRATA
   - Mammalia
   - Aves
   - Reptilia
   - Amphibia
   - Pisces

2. MOLLUSCA
   - Cephalopoda
   - Pteropoda
   - Pulmogasteropoda
   - Branchiogasteropoda
   - Lamellibranchiata

3. MOLLUSCOIDA
   - Ascidioida
   - Brachiopoda
   - Polyzoa

4. ANNULOSA
   - Insecta
   - Myriopoda
   - Arachnida
   - Crustacea
   - Annelida

5. ANNULOIDA
   - Scolecida
   - Echinodermata

6. CŒLENTERATA
   - Actinozoa
   - Hydrozoa

7. PROTOZOA
   - Infusoria
   - Spongida
   - Rhizopoda
   - Gregarinida

In explaining the advance of zoological knowledge as exhibited in these two tables, attention may first be directed to the changes which have been made in the smaller subdivisions or *classes*. The vertebrate classes have suffered the least alteration—the class Reptilia having been merely divided into the proper Reptiles, such as the snakes, turtles, and lizards; and the Batrachia or Amphibia, represented by the frogs and salamanders. Amongst the Mollusca, the class of Gasteropods has been divided into those which breathe by lungs, and those which respire by gills, i. e. into the Pulmo- and Branchio-gasteropoda. The class Acephala, which included the testaceous and tunicated orders of Cuvier, are subdivided into two corresponding classes, named the Lamellibranchiata and the Ascidioida, the latter of which has been placed in a new subkingdom. The class Brachiopoda has also undergone a similar transposition. The class Cirrhopoda, or barnacles, has been transferred as an order to the Crustacea, belonging to another, the Annulose, subkingdom. Of the Articulate classes, one order amongst the insects, named the Myriopoda, is separated from them to form a distinct class; whilst, as already mentioned, the class Crustacea is reinforced by the Cirrhopods. The Radiate classes have undergone the most notable changes, some of them having been much divided, and all rearranged, in other or new subkingdoms. The Echinodermata are otherwise unchanged. The Intestina are associated with certain minute marine worms, and with the rotiferous animalcules from Cuvier's

Infusoria, to form a class named Scolecida, placed next below the true worms or Annelida. The Acalepha are made to form part of the new class Hydrozoa. The Polypi are split up and separated in three directions; the order of coralline polyps form the class Polyzoa (sometimes named the Bryozoa); the order Actinia or sea-anemones becomes the class Actinozoa; whilst the order of gelatinous polyps, represented by the hydra, is united with the Acalepha in the class Hydrozoa. Lastly, of the Infusoria of Cuvier, one order, the Rotifera, passes upwards to join, as already mentioned, the Scolecida; whilst the others form the present Infusoria, after discarding certain algaceous vegetable organisms; finally, certain remaining lowly organised animal bodies constitute the new classes Spongida, Rhizopoda, and Gregarinida.

Such being the modifications in those carefully defined groups which constitute the classes of the animal kingdom, we may now direct attention to the resulting changes in the larger groups or *subkingdoms*. The Vertebrate subkingdom remains intact. The Mollusca of Cuvier, diminished by the Cirrhopods, which pass into the Crustacea of another subkingdom, and increased by the Polyzoa, the radiate coralline polyps of Cuvier, present the same general limits as the two subkingdoms, Mollusca and Molluscoida, of the new arrangement, the line of partition between these latter being drawn between the Lamellibranchiata and Ascidioida, i. e. through the centre of the Acephalous Molluscs of Cuvier. The Articulate subkingdom of the French zoologist remains undivided, as the Annulosa, reinforced only by the Cirrhopods, which, as just stated, are now included in the Crustacea. The Radiate subkingdom, corresponding, it may be remarked, with the so-called Zoophytes of many writers, disappears; for its classes are completely broken up and distributed into other or new subkingdoms. Thus, the coralline polyps are transferred to the new subkingdom Molluscoida, and form the lowest Molluscoid class. The new subkingdom Annuloida includes the Echinodermata, with the Intestina and rotiferous order of the Infusoria, the two latter being joined under the name Scolecida. The new subkingdom, named Cœlenterata, comprehends a second group of the polypi, namely, the Actinia, under the title Actinozoa, and also the gelatinous polypi, which, with the Acalepha, form the Hydrozoa. Lastly, the new subkingdom Protozoa includes the Infusoria, with the exception of the Rotifera, which ascend to the Annuloid subkingdom, and also the three lowest new classes, the Spongida, Rhizopoda, and Gregarinida.

The preceding changes are due to the labours of many zoologists. Thus, Carus suggested the term Protozoa, whilst Von Siebold and his followers separated that group into a distinct subkingdom. The Cœlenterate subkingdom and its limits were suggested and defined by Frey and Leuckart. The Molluscoid and Annuloid subkingdoms owe their origin to Milne-Edwards and Huxley, the coralline polyps, or Polyzoa, especially, having been placed in their new position owing to the researches of the former naturalist. The Cirrhopods were long since transferred to the Crustacea by Grant; and the Intestina have, by many authors, been removed to the neighbourhood of the true worms. With regard to the worms, some zoologists, as, e. g., Gegenbauer, have even placed them in a distinct subkingdom named Vermes; whilst the Echinodermata have also received similar treatment. Even the Infusoria,

as already mentioned, have been separated from the other Protozoa as if forming a group of higher importance than a mere class (Huxley). The general relations between the *subkingdoms* of the Cuvierian and of the modified arrangement here adopted may be expressed by the following schemes :—

Cuvierian Arrangement.

VERTEBRATA

MOLLUSCA ARTICULATA

RADIATA

Modern Arrangement.

VERTEBRATA

MOLLUSCA ANNULOSA

MOLLUSCOIDA ANNULOIDA

CŒLENTERATA

PROTOZOA

General Characters of the Subkingdoms.

Vertebrata. The vertebrate animals are distinguished by the possession of an internal skeleton, the central part of which, the back-bone, forms a longitudinal bony or cartilaginous axis, usually divided into segments called *vertebræ*, the entire axis being named the *vertebral column*; anteriorly, this internal skeleton is expanded into the *cranium*; laterally, the vertebral column frequently presents symmetrical pieces, named *ribs*; and, besides these, there may exist two or four, but never a greater number, of larger lateral appendages, placed symmetrically on each side, and named *limbs*. Within the vertebral column, and (supposing this to be placed horizontally), above the more solid part formed by the so-called bodies of the vertebræ, is an elongated cavity continuous in front with the cranial cavity, and named the *neural* cavity, because it contains the great nervous axis composed of the *brain and spinal cord*; whilst below the vertebral column, and enclosed within the ribs, when these exist, is a larger cavity called the *hæmal* cavity, because it lodges the chief organs of the circulation, the heart and great bloodvessels; but besides these, it also contains the digestive, absorbent, respiratory, and reproductive organs, as well as the cords and ganglia of the *sympathetic nerves*: it forms therefore a distinct *perivisceral* cavity.

The nervous system is more highly developed than in the other subkingdoms; not only are the senses more perfect, but the brain or cerebral portion of the nervous system, is highly developed, and exhibits a capacity to be associated with superior mental endowments. The jaws are formed by modified parts of the head, have no true analogy to limbs, and move vertically; teeth are often present, composed of dentine or modified bone

covered with other hard material formed from the mucous membrane of the mouth; they constitute parts of the external skeleton. The alimentary canal, besides possessing a distinct stomach, salivary glands, and liver, is also provided with a pancreas. Special absorbent or lymphatic vessels exist, ending in a true blood-system of vessels, and containing a fluid in which colourless corpuscles are present; the absorbents proceeding from the alimentary canal, convey chyle, and are named lacteals. The circulating system is highly developed, consisting of a heart divided into two, three, or four cavities, connected with distinct arteries, capillaries, and veins, and containing blood provided with both white and red corpuscles: a portal system of veins, transmitting blood from the alimentary canal to the liver, is also peculiar to the Vertebrata. In the lowest vertebrate animal known, viz. the Amphioxus or lancelet, an exception is found in regard to the blood and the heart, the blood containing only colourless corpuscles, and, in place of a single heart, numerous contractile sacs are found in the course of the chief bloodvessels. One at least of the so-called vascular glands, viz. the spleen, is always present in the Vertebrata. The law of bilateral symmetry prevails in a most perfect manner, in the animal organs of locomotion and sensation; the organs of the senses are also double, excepting in the case of the single olfactory organ of the Amphioxus. Some of the Vertebrata, viz. the Mammalia, Aves, Reptilia, and higher Amphibia, breathe by lungs only; of the rest, a few of the Amphibia respire by lungs and gills, whilst all of the lowest class, Pisces, breathe by gills alone. Certain distinctive peculiarities, derived from the mode of development of the body of the embryo, and of the so-called visceral arches, belong to this subkingdom; these will be described in the chapter devoted to the subject of Development.

The vertebrate animals have been variously subdivided into groups, larger and fewer in number than the classes. Thus, the Mammalia and Birds form the so-called *warm-blooded* Vertebrata; whilst the Reptiles, Amphibia, and Fishes constitute the *cold-blooded* Vertebrata. A more scientific division requires, however, the recognition of the intimate connection between the Birds and Reptiles. It has been pointed out that the classes Mammalia, Aves, and Reptilia have, at no period of their existence, gills or organs intended for aquatic respiration; hence they have been grouped together as the *Abranchiate* Vertebrata; whilst the Amphibia and Pisces, always having temporary or permanent gills, have been included under a second group of *Branchiate* Vertebrata: these two groups are also distinguished by certain embryonic characters, which can only be alluded to here, the former possessing the so-called amnion and allantois, whilst the latter is destitute of both those structures, or possesses merely a rudimentary allantois. By another mode of classification (Huxley), the Abranchiate classes of the Vertebrata are separated into two groups, the one containing the Mammalia, and the other the Birds and Reptiles. The higher group, *Mammals*, have no branchiæ, but possess an amnion and allantois: they have two condyles to the occipital bone, a well-developed basi-occipital bone, no parasphenoid bone, and a simple lower jaw articulated with the squamosal and not with the quadrate bone; they possess mammary glands and non-nucleated coloured blood corpuscles. The lower group, *Sauroids*, comprising the Birds and Reptiles, likewise have no branchiæ, but possess an amnion

and allantois: they have no parasphenoid bone, only a single occipital condyle, and a complex lower jaw articulated to the quadrate bone; they are unprovided with mammary glands, and have nucleated coloured blood corpuscles. A third distinct group, *Ichthyoids*, including the Amphibia and Fishes, possess branchiæ at some period of their existence, have no amnion, either no allantois or merely a rudimentary one, a parasphenoid bone in the skull, and nucleated coloured blood corpuscles.

It would be beyond the scope of this work to define the classes of the animal kingdom; but the characters of many of their internal organs will be given in the subsequent chapters on the special functions. With regard to the class *Mammalia*, however, in which man is included, an enumeration of the various orders of animals contained in that class is requisite, since frequent reference is made hereafter to the structure of the digestive and other organs in those groups. As usually defined, these orders are twelve in number, viz. the *Bimana*, *Quadrumana*, *Carnivora*, *Cheiroptera*, *Insectivora*, *Rodentia*, *Ruminantia*, *Pachydermata*, *Edentata*, *Cetacea*, *Marsupialia*, and *Monotremata*. The first of these orders, *Bimana*, contains the genus Homo, or Man, alone, who is regarded by the highest zoological authorities as of one species, although presenting many varieties. By Linnæus, however, Man was placed, together with the so-called Quadrumana, the apes, baboons, monkeys, and lemurs, and even the Bats, in a single order named the *Primates*. The above-named classes are grouped into three divisions; the first, named the *Deciduate-placental* Mammalia, includes the Bimana, Quadrumana, Carnivora, Cheiroptera, Insectivora, and Rodentia; the second, called the *Non-deciduate-placental* Mammalia, comprises the Ruminantia, Pachydermata, Edentata, and Cetacea; the third, named the *Implacental* Mammalia, includes the Marsupialia and Monotremata.

Mollusca. These animals, named from their *soft* structure (*mollis*, soft), have no internal segmented skeleton, like the Vertebrata; nor is the body segmented like that of the Annulosa, to be presently described; on the contrary, it is generally broad in proportion to its length, and belongs to what has been termed the *massive* type. They have no external hairs, feathers, scales, or horny or osseous plates; their soft integument is commonly protected by an external calcareous *shell* composed of many layers secreted, one within the other, by the surface of a part of the body named the *mantle.* They have no jointed limbs, but the locomotive organs are always soft and merely *musculo-cutaneous*, usually forming the so-called foot or feet. The nervous system consists of scattered ganglionic masses, commonly disposed in three principal pairs, named, from their position or function, the *cerebral*, *pedal*, and *parieto-splanchnic ganglia.* The cerebral ganglia are very small in comparison with the brain of the Vertebrata, and there is no spinal cord. These ganglia are joined together by commissural nerve cords; the cerebral ganglia, placed above the œsophagus, are connected by two cords, which pass down on the sides of the gullet, with the pedal ganglia, so that the gullet is enclosed or surrounded by the anterior part of the nervous system, or passes through it; longitudinal commissures also connect the cerebral with the parieto-splanchnic ganglia, but these latter and the pedal ganglia are not necessarily connected by direct commissures. The alimentary canal is provided at the mouth with soft non-segmented tentacles; it lies, as in the Vertebrata, in a distinct cavity named the

perivisceral cavity, and is furnished with salivary glands and a largely developed liver. The heart, dorsal in situation, contains two cavities, and is connected with the systemic bloodvessels; the blood is corpusculated but colourless. Most molluscs being aquatic, breathe by gills, but some terrestrial genera possess pulmonary air-sacs.

In the highest Mollusca, the cephalopods or cuttle-fishes, there is frequently found a rudimentary cranium supporting the cerebral ganglia, and sometimes an internal horny or calcareous mass which may be taken to represent an internal skeleton.

The Molluscous classes, Cephalopoda, Pteropoda, Pulmogasteropoda, and Branchiogasteropoda, constitute a group named *Odontophora*, because they possess a peculiar apparatus in the mouth, armed with teeth, and movable, and sometimes called a tongue, but more appropriately the *odontophore* (Huxley). The remaining class, Lamellibranchiata, form a group destitute of the odontophore, and characterised by having a right and left bivalved shell and two lamelliform gills on each side of the body.

In the various classes of Mollusca, different parts of the soft body and appendages, which have received different names, are variously developed. Moreover, the alimentary canal follows such developments of the body, and thus becomes not only elongated, but bent; sometimes the concavity of the bend is directed towards the abdominal or under surface, and, as the chief nervous motor ganglia are placed on that side, such a bend is named a *neural flexure*, as seen in the Cephalopoda, Pteropoda, and Pulmogasteropoda; whilst sometimes, the concavity is turned towards the dorsal region, or in the direction of the heart, and then it is termed a *hæmal* flexure, as in the Branchiogasteropoda: in the Lamellibranchiata it is at first neural, but is afterwards specially modified.

Molluscoida. The comparatively small subkingdom, Molluscoida, consists of animals which, as implied by their name, have close relations with the Mollusca, and were commonly classified with them; but, as suggested by Milne-Edwards, they may be more conveniently placed in a separate subkingdom, being much simpler in their organisation. The nervous system consists of a *chief ganglion* with a few scattered ganglionic masses, or of a *single ganglion* only. The principal or single ganglion, as the case may be, is placed close to the oral aperture or mouth, sometimes having a nervous cord around the gullet. The alimentary canal is much flexed on itself, and sometimes is only provided with one opening, viz. the mouth. When an outlet also is present, it is placed, as a rule, near the mouth, the chief ganglion usually being placed between the two openings. A heart is not always present, and when it exists, is composed of but a single cavity. The oral aperture, except in one group (Appendicularia) is always surrounded with numerous *tentacles*, which are *ciliated*, and therefore probably respiratory, and are arranged either in a circle, or else upon long arms, or upon a band or ridge shaped like a horse-shoe. Moreover, the mouth opens not directly into the œsophagus, but first into a long and sometimes very wide chamber or pharynx; and sometimes other so-called atrial or respiratory chambers are met with. In the Brachiopoda and Polyzoa the alimentary canal presents a neural flexure; in the Ascidioida, a hæmal flexure.

The classes of the Molluscoid subkingdom, all of which are aquatic, and mostly marine, consist of the Ascidioida, which include the tunicated

marine animals, the Brachiopoda, and the Polyzoa or coralline polyps. It is in the Brachiopoda that the alimentary canal is sometimes destitute of any outlet, and that the remarkable contractile sacs, named pseudo-hearts, exist.

Annulosa. This subkingdom is distinguished, as its name implies, by its component animals having a segmented body, i. e. a body composed of a series of more or less distinctly marked *annular segments, or rings*, named *somites*, joined one behind the other. The body, therefore, of an Annulose animal is usually elongated, or belongs to the *longitudinal* type. Moreover, the surface of these segments is always firm, and sometimes even horny or calcareous, so as to form a dermal skeleton. In the higher classes, articulated or jointed limbs, also composed of external hardened integument with the soft parts within, and arranged symmetrically in lateral pairs, are met with. The central parts of the nervous system consist of numerous *pairs of ganglia* arranged one behind the other in a longitudinal direction, and connected by longitudinal cords. Usually each pair of ganglia is connected by a transverse commissural cord; but sometimes they are fused into a single mass, in which case, the double longitudinal cords are likewise blended. The first pair of ganglia, named *supra-œsophageal* or *cerebral*, are placed above the gullet, and the cords which pass downwards and backwards to the second pair of ganglia, named *sub-œsophageal*, embrace the sides of the gullet, which, therefore, as in the Mollusca, is completely surrounded by nervous matter, and is accordingly said to pass through or perforate the anterior part of the nervous apparatus: the remaining ganglia, with their longitudinal connecting cord or cords, are placed entirely below the alimentary canal, i.e. along the under side of the body. In the higher forms, the sensory organs are highly developed, and a distinct contractile dorsal vessel, segmented, and provided with valvular openings leading into the *perivisceral cavity*, takes the place of the well defined heart found in the Mollusca and Vertebrata. The blood is sometimes colourless and sometimes coloured, and contains a few corpuscles.

As shewn in the scheme of the subkingdoms already given, the Annulosa may be regarded as standing below the Vertebrata, side by side with the Mollusca, though, in some respects, the Mollusca present the higher organisation. As the Mollusca have been divided into a larger and higher group, viz. the Odontophora, and a smaller and lower one, consisting only of the Lamellibranchiata, so also the Annulosa may be similarly subdivided. Thus, the Insecta, Myriopoda, Arachnida, and Crustacea, form a large group, named *Arthropoda*; sometimes, even, raised into a distinct subkingdom under that name, or under the title Articulata: they are characterised by always having articulated limbs. (ἄρθρον, *arthron*, a joint, πούς, *pous*, a foot). The smaller group consists of the class Annelida only, which have a softer integument, no jointed limbs, but simple lateral and symmetrical appendages, such as cirrhi or setæ. The rest of their organisation, like that of the Lamellibranchiata, in comparison with the Odontophora, also presents a different and lower type of organisation than the Arthropoda; and, indeed, they have by some been separated from the latter to form a distinct subkingdom under the name Vermes. They are, however, naturally associated with the higher Annulosa, from the annulated structure of their bodies, and the

double ganglionated cords of their nervous system. The Arthropoda are further distinguished by the perfect bilateral symmetry, not only of the body and the organs generally, but even of their digestive and reproductive systems; also by the complex structure of the head, and by their highly developed organs of vision: the head has been shewn to be composed of from four to six modified annuli or somites (Huxley); the jaws move transversely, and feelers or antennæ always exist; lastly, no vibratile cilia have been seen either in the embryonic or adult condition of any of the Arthropoda. On the other hand, the Annelida, instead of a hard external skeleton and jointed limbs, have a soft body with simple appendages; the head never contains even four modified somites (Huxley); he organs of sense, especially the eyes, are very simple; there is no listinct valved dorsal vessel communicating with the perivisceral cavity; nost of them possess, either in the embryonic or adult condition, ribratile cilia on, or in some part of, their bodies; and, lastly, they are nearly all provided with peculiar vessels, named *pseudo-hæmal*, which requently contain a *coloured* corpusculated fluid.

Annuloida. Standing below the Mollusca, we found simpler softkinned animals grouped together under the name Molluscoida, as sugested by Milne-Edwards; and so below the Annulosa are arranged, by Iuxley, under the name Annuloida, which is intended to show their elations with the Annulosa, the class Scolecida, containing certain narine worms, the entozoa or parasitic worms, and the rotiferous nimalcules, and the class Echinodermata, or star-fishes. These Annuoid animals approach the lowest Annulosa, i.e. the Annelides, in the vorm-like form of the bodies of many of them; in the frequent presence f cilia, at least in the embryo condition; in the possession of a peculiar et of vessels, named the *water vessels*, in the Scolecida, and the *ambulacral essels,* in the Echinodermata, which may represent the pseudo-hæmal essels of the Annelida. But the Annuloida are distinguished from the nnulosa by the imperfect segmentation of the body, or by the complete bsence of segmentation, and by the non-existence of bilateral symetrical limbs or appendages. The nervous system never presents the ouble longitudinal ganglionated cord, but consists of either one, two, r four *supra-œsophageal ganglia* situated in the fore-part of the body, bove or upon the gullet, from which delicate branches merely ramify orwards through the head, and backwards through the body; in the chinodermata, in accordance with their horizontally radiated form, the anglia, which might be termed *circa-œsophageal*, are proportionally nultiplied, are connected with cords surrounding the oral aperture, and ive off radiating branches. Eye-spots are present in the Rotifera and n some Echinodermata, but the other sensory organs are rudimentary r absent. In most of the Annuloida, moreover, that remarkable node of development is observed, by which the ova do not immediately orm perfect animals, but larvæ or embryonic forms, within which, by a ubsequent process of evolution, perfect animals are produced. This ind of development is known as *alternate generation*.

Cœlenterata. This extremely natural group, established as a subingdom by Frey and Leuckart, consists of animals, the bodies of which ave a much simpler structure than those even of the lowest Annuloid or west Molluscoid animals; although the radiated form, common to both e class Actinozoa or sea-anemones, and the class Hydrozoa, which

includes the Medusæ, Acalepha or sea-nettles, and Hydroid Polyps, suggests resemblances with the Echinodermata on the one hand, and with the Polyzoa on the other. The body of the Cœlenterata is hollow; the alimentary canal, destitute of special glands, is extremely short and simple, for it has but one external aperture, viz. the oral opening or mouth, its hinder end opening widely into the cavity of the body itself; hence the name Cœlenterata (κοῖλος, koilos, hollow; ἔντερον, enteron, intestine). The walls of the body are also characteristically simple, being composed of an outer layer named the ectoderm, and an inner layer named the endoderm; both are composed of nucleated cells, and apparently in the simplest forms, as in the Hydra, possess the same physiological properties, for they are equally capable of digesting food received into the hollow of the body, even when this is turned inside out. Around the oral opening are usually found numerous prehensile *tentacles*, usually hollow, and *never provided with vibratile cilia* upon the surface, like the tentacles of the Polyzoa. Most of the Cœlenterata have, in their ectoderm, little oval elastic sacs containing, besides fluid, a long barbed and serrated filament, which is projected beyond the sac on any irritation, and so acts offensively or defensively, destroying soft animal prey, and even irritating the human skin. These sacs are named *nemato-cysts* or *thread-cells*, and their irritating qualities have given rise to the term sea-nettles, applied especially to the Acalepha. Somewhat similar bodies, it may be added, are found in certain Mollusca and Scolecida. The nervous system of most of the Cœlenterata has hitherto escaped detection; but in the Ctenophora or ciliograde forms, such as the Beroe, it consists of a *single* or *compound ganglion* placed in the centre of that part of the body opposite to the oral aperture, and of nervous filaments radiating from it. Doubtful ganglia have been described as existing in the base or attached part of some of the Actinozoa or sea-anemones. No organs of circulation exist; but the cavity of the body is prolonged in the form of canals, even into the tentacles, and sometimes these are lined with cilia, so that they may not only convey nutriment digested in the short alimentary canal, and passed at once into the cavity of the body, but may, as well as the general surface, act as respiratory organs.

Protozoa. The remaining and lowest classes of animals constitute the subkingdom Protozoa, which includes the Infusoria, the Spongida or Porifera, the Rhizopoda or Foraminifera, and the Gregarinida. The Protozoa agree in the marked simplicity of their organisation, as compared even with the lowest of the Molluscoid, Annuloid, or Cœlenterate animals. With the Annuloida, however, some of them present a certain affinity, as shown by the class Infusoria having at one time been made to include the rotiferous or wheel-animalcules of the Annuloid subkingdom. The Protozoa have, so far as is known, *no nervous system*; they have no proper alimentary canal or circulating organs; nor do any of them contain a large body-cavity, like the Cœlenterata, bounded by two layers, an ectoderm and an endoderm. They are composed of a minute mass, or of aggregate masses, of a soft substance, usually designated *sarcodous*, possessing more or less contractility; within this there is often found a central nucleus, and frequently one or more peculiar cavities of variable size, named *contractile vesicles*. Nearly all inhabit either fresh or sea water, but a few live in the interior of more highly organised animals

Most of them possess cilia used either as locomotive organs, or for the ›urpose of creating currents in the water in which they live. They are ısually multiplied by the simplest forms of development, such as gemnation or fission, as will be hereafter explained.

Of the Protozoa, the class Infusoria certainly stand higher than the ·est; their soft sarcodous substance is firmer on the surface than in the nterior, where it is sometimes almost fluid. In the typical forms, a mall orifice on the surface, surrounded by cilia, constitutes a sort of nouth; and hence the Infusoria have been grouped together under the ıame of *Stomatoda*, or Stomatode Protozoa. This mouth leads into a hallow cavity or short tube, which ends abruptly in the soft central arcode, and which is regarded as a *gullet*, or rudiment of an alimentary anal. The contractile vesicles in their interior, sometimes also named *acuoles* or *water-receptacles*, are more numerous than in other Protozoa. 'he Infusoria are also particularly distinguished by the importance of ıeir cilia, which are sometimes single, but more frequently very umerous on the surface of their bodies, and which serve not only for ›comotion, but also sometimes to direct the food into their short gullet. 'y the possession of locomotive and other cilia, they approach the lotifera and other Scolecida; also by the analogy between their con:actile vacuoles, which are sometimes ramified, and the water-vessels of ıese Annuloida; and, lastly, by their occasionally undergoing, like the :tter, a process of *encystation*, preparatory to developing young in their ıterior. They are distinguished from the other Protozoa by the eculiar possession of the so-called nucleus and nucleolus, two parts ssentially concerned in that form of the reproductive process known as *mjugation*. The Infusoria, like the remaining Protozoa, are developed so by gemmation and by fission.

The remaining Protozoa present no oral aperture or mouth, and hence ıve been grouped together under the name *Astomata*, or Astomatode rotozoa. They are, in all respects, more simple in structure than the ıfusoria, their sarcodous substance being destitute of any firmer outer ›rtion or envelope, but being uniformly soft throughout, and somemes containing only a single contractile water-vesicle. The Spongida nsist of aggregations of these minute sarcodous masses, which are metimes ciliated, and are always, as well as the allied sarcodous ıicellular independent animals, such as the Amœba, capable of varying eir form by thrusting out broad or narrow processes or lobes, somenes named feet. The Rhizopoda are furnished with beautiful riaceous or siliceous shells, sometimes simple, sometimes manyambered: in them, the sarcodous processes are extremely long and read-like, often very numerous, like roots (*rhizon*, a root; *pous*, a ›t), and frequently coalesce at their extremities; they are named *eudopodia*; they are often thrust through the minute openings in the rforated shells, which have suggested the name Foraminifera given to ese interesting and abundant animals. Lastly, in the Gregarinida, the ft body is destitute of envelope, contractile processes or pseudopodia, d contractile vacuoles, and presents only a nucleus in its interior, with contained nucleolus. They constitute the lowest and simplest forms the animal series, being unicellular, and composed of naked nucleated rtions of sarcode or protoplasm, elsewhere mentioned as *gymnoplasts*.

The reproduction of these lowest Protozoa is also extremely simple, being sometimes, at least apparently, non-sexual, a certain portion of the parent animal, which first becomes encysted, undergoing direct transformation into a mass of young.

Position of Man in the Animal Series.

Such being the outlines of the vast array of the animal kingdom, the zoological position of man is, as we have seen, at its very summit; for he occupies the highest position in the class Mammalia, in the subkingdom Vertebrata. Whether he should be arranged with the Quadrumana in one order, the *Primates* (Linnæus), or be separated from them to form a distinct order, *Bimana* (Blumenbach, Cuvier), or be still further distinguished from the animals by being placed in a separate subclass, *Archencephala* (Owen), is a purely zoological question, not to be discussed here. Whichever view comes to be ultimately adopted, the anatomical characteristics of man are well marked, even when his structure is compared with that of the highest anthropoid apes. His structural peculiarities will be found to depend chiefly on the following conditions, viz. the perfect adaptation of his skeleton and muscles to the erect attitude maintained upon the hinder extremities exclusively, so as to set entirely free the anterior limbs for special, but non-locomotive, purposes; the comparatively soft nature of his food; his want of special organs of offence; and, lastly, the higher organisation of his brain to fit it to become the instrument of superior intellectual endowments. These points will be hereafter respectively considered in the chapters on locomotion, mastication, and the functions of the brain. It may, however, here be added, that the general form of the human body and its parts is rounder, fuller, and more richly modelled, than that of any of the animals nearest to him; and that his skin is almost destitute of hairy covering. Physiological, social, moral, and psychical differences also distinguish him in a remarkable manner from any animals. Such are—his slow growth, associated, doubtless, with the ultimate perfection of his organisation and powers; his necessarily long-continued dependence on his parents; his adaptability to all kinds of climate, soil, and food; his marked improvability, dependent on the subjection of his instincts to his reason; his perception of the abstract beyond the concrete; and, as consequences of this, the formation of abstract ideas, the invention of speech and language

ommunication of mind with mind, the preservation and ransmission of knowledge from one generation to another, moral sense of duty to others and to himself, and a conciousness of relations, mysterious though they be, to the resent, to a past and a future, to the finite, and to the Infinite.

ypes, Laws of Form, Homologies, Analogies, Unity in Variety, Genetic Relations.

The zoological relations of man with the entire animal ingdom, are necessarily associated with anatomical and phyiological resemblances and differences more or less marked n special cases. The determination of these is the proper bject of comparative anatomy and physiology. The former cience has been cultivated so far as to lead to the discrimiation of certain general *plans* or *types* of form observable n the animal series, which are indicated in the several subingdoms. At least, there can be little doubt as to the pparent distinctness of the vertebrate, molluscous, annulose, œlenterate, and protozoic types ; though it is possible that the olluscoid and annuloid groups are subtypical, and attached espectively to the molluscous and annulose types. The ideal lans of these types of course involve every *leading* or essenial feature in their structure ; but one very simple view of hem, is that expressed by a comparison of transverse sections hrough the body in each case, as is shown in the following iagrams, fig. 45.

Thus, a transverse diagrammatic section of the body of a *Vertebrate* nimal, V, shows two chambers, or *perivisceral cavities*, an upper smaller ne, and a lower larger one, separated from each other by the more solid r *axial* part of the vertebral column, occupying the position of the soalled dorsal cord of the embryo. In the upper tubular chamber, the *eural* cavity, lies the section of the great nervous axis or centre; in e lower chamber, or *hæmal* cavity, are lodged the double or laterally ymmetrical sympathetic nerves, above, the alimentary canal in the iddle, and the heart, or central organ of the blood system, below.

A transverse section of a *Molluscous* animal, M, shows but a single ody-cavity or perivisceral cavity, in which the heart is placed above, e alimentary canal in the middle, and the chief portions of the nervous ystem, i. e. the double laterally symmetrical pedal and parieto-splanchic ganglia, at the lower part.

A similar section of an *Annulose* animal. A, presents also a single erivisceral cavity, having, as in the Mollusc, the alimentary canal in the iddle, the double ganglionated nervous cords below, and the elongated orsal circulating vessel above.

On comparing the Molluscous and Annulose types, it appears that the longitudinal segmentation of the latter is the chief difference, the typical

Fig. 45.

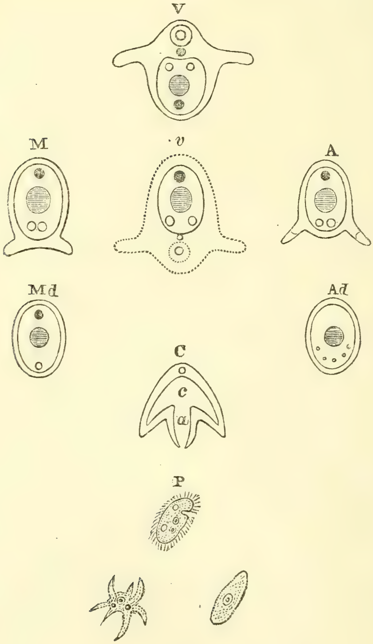


Fig. 45. V. Transverse section of Vertebrate type or plan. *v*. The same inverted. M. Transverse section of Molluscous type. A. ditto Annulose. Md. ditto Molluscoid. Ad. ditto Annuloid. C. Longitudinal section of Cœlenterate plan—*a*. alimentary canal; *c*. body cavity. P. Diagrams of Infusorial, Amœbous, and Gregarinidous Protozoic plan, highly magnified. In the upper six of these diagrams, the alimentary canal is shaded with cross lines; in them, and in the plan C, the nervous cords are left as open rings; the heart or circulatory vessel, when present, is represented black.

plan being otherwise the same. On comparing these two with the Vertebrate type (which can best be done by supposing the latter to be *inverted*, so that its abdominal surface is turned upwards, as at *v*), it will be seen that their single perivisceral cavity, with its contents, appears to represent the hæmal cavity of the Vertebrate animal and its

contents; and that the vertebral column, or dorsal cord, the neural cavity, and its great nervous axis, the cerebro-spinal centre, are altogether superadded parts in the Vertebrate type.

A transverse section through a *Molluscoid* animal, Md, shows also a single perivisceral cavity, having the alimentary canal in the middle, the single or chief ganglion on the side next the locomotive organs, and the rudimentary heart on the opposite side; but these sides are no longer obviously under and upper, as in the Mollusca.

No single diagram will represent the diverse plans of the Annuloid animals. In the highest forms, however, there is no true heart or central circulating organ, and the chief nervous ganglion sends off nervous cords scattered through the body; but there is still a central alimentary canal, distinct from and lying in a perfect perivisceral cavity.

The subtypical position of these two last forms, in regard to the Mollusca and Annulosa, is obvious; of these plans, or types, they are simplifications, or, as in the radiated forms of the Echinodermata, modifications in points of detail.

The *Cœlenterate* type is altogether different and lower. A transverse section will no longer reveal its plan. A *longitudinal* section, C, shows the complete absence of a perivisceral cavity, for the alimentary canal, *a*, now ends in, or is part of, the general cavity of the body, *c*; there is no heart or central circulating organ; and the nervous centre, when such can be detected, is placed at the end of the animal opposite to the oral aperture.

Lastly, the *Protozoic* type is still more simple. A section of their bodies no longer indicates even a distinct body-cavity. A diagram of the highest, or Infusorial form shows a unicellular bi-nucleated sarcodous mass, with a firm exterior bearing cilia, a short gullet ending abruptly in the mass, and one or more internal contractile vesicles; but no nervous or circulatory apparatus. The Amœbous form has not even a short gullet; but the soft mass, now without a distinct envelope, and changeable in its shape, has a single or double nucleus, and sometimes also a contractile vesicle; aggregates of such masses may occur. Lastly, the lowest, or Gregarinidous form consists of a simple gymnoplast, or naked nucleated cell, composed of a minute mass of protoplasmic sarcode, containing a single nucleus, with its included nucleolus.

The science of *philosophical anatomy* further endeavours to penetrate the fundamental laws at work in these several plans of construction. Considered generally, it is seen that all animal forms exhibit a more or less *axial* mode of growth; that all are more or less perfectly *bilaterally symmetrical*, even the spirally convoluted Gasteropodous Molluscs presenting two, though unequal, halves, and the radiating Echinodermata also exhibiting an imaginary *median plane* of partition. It is further seen that the *spheroidal* form is common amongst simple animals, ova, and commencing tissue cells; the *radiate* form, in many of the lower animals; and *spiral* arrangements, in others, as well as in the organs or parts of animals higher

in the scale: lastly, *repetitions* of similar parts are found to prevail in the elongated animals, and in many organs and tissues.

Furthermore, it is shown, on comparison, that like parts in the same animal, or in different animals, may be extremely modified in form and structure, to suit different purposes, and yet not lose their *essential identity*; in such case, they are said to be *homologous* parts. Thus, each vertebra, or vertebral segment, is homologous with every other vertebra, however highly developed these may be, as in the back, or however they may be simplified, as in the sacrum or coccyx: even the cranial segments, specially modified as they are, have been regarded by many as homologous with vertebræ. Again; the upper limb of man, and its several bones, are homologous with the lower limb and its bones, part for part, although the one is fitted for prehension and the other for locomotion. The shoulder bone and collar bone together are the homologues of the hip bone; the humerus, of the femur; and the radius and ulna, of the tibia and fibula. Again, the carpus and metacarpus are homologous with the tarsus and metatarsus; the three phalanges of the four fingers with those of the four outer toes; and, lastly, the thumb, having two phalanges, is the homologous part to the great toe, which also has two phalangeal bones. The same law of fundamental homology is evident in comparing, not merely the parts of the same animal, but those of different animals of the same type with each other: thus the upper prehensile limb of man is homologous with the equally prehensile arm of the ape, with the locomotive fore-limb of the mammalian quadruped and reptilian lizard, with the wing of the bat and the more specially modified wing of the bird, with the anterior flipper of the seal, the single flipper of the porpoise, the paddle of the turtle, the fore-foot of the newt, and the pectoral fin of the fish; for all these parts, however different in form and use, are modifications of the same fundamental portion of the vertebrate frame, i. e. of the *anterior lateral appendage.* So also the lungs of the mammalia, birds, reptiles, and amphibia are homologous with the air-bladder of certain fishes, though this ceases in most cases to be in any way a respiratory organ. Passing from the Vertebrate to some other type, as e.g. to the Annulose, we find homology in the different somites of an insect or a crustacean, however they may be modified or fused together; and so also the antennæ, the jaws, the large pincers, and the locomotive or swimming feet of the lobster, are obviously homologous parts

resulting from the modification of typical lateral appendages. Homologies also are apparent between like parts of animals constructed upon totally different types; but they are fewer in number and less apparent, sometimes obscure or even doubtful; thus there can be no doubt that the stomach, salivary glands and liver of the Mollusca, and even similar parts of the still lower subkingdoms, are homologous with the alimentary canal and its appended glands in the Vertebrata; so also the supra-œsophageal ganglion of the Mollusca and of the Annulosa, with which the nerves of special sense are connected, is probably homologous, on the one hand, with the sensory portion of the cerebrum of the Vertebrata, and is certainly so, on the other, with the single ganglion of the Molluscoida, and of the Annuloid Rotifera. But with regard to the locomotive organs in animals belonging to different subkingdoms, the homologies are not evident, as e.g. between the legs of quadrupeds, the legs of insects, and the locomotive organs of the Mollusca. Further, as already mentioned, though the heart of the Mollusca, and the dorsal vessel of the Annulosa, are really the centres of the circulating system in those animals, it is doubtful whether they are strictly homologous with the heart of the Vertebrata; for the circulating organs in these lower animals are by some regarded as possibly homologous with the lymphatic system of the Vertebrata, in a few of which animals lymphatic hearts are met with.

Homology must not be confounded with another, but less important, relation which often exists between the parts of animals, and which is designated by the term *analogy*. Parts or organs sometimes perform corresponding functions, and yet are not homologous structures; they are then said to be analogous parts. Thus the lungs of the Vertebrata are analogous to the pulmonary sacs of certain snails, and to the air-sacs of spiders; but, from their position and connections, are evidently not homologous parts. So too the wings of the bird and those of the insect, and, again, the gills of the fish and the gills of the lobster, are analogous but not homologous organs.

Although the essential resemblances between man and the higher animals, on the one hand, and the lowest animals, on the other, become at length so obscure, that the homology between a vertebrate animal and a protozoon is no longer recognisable, so far as special *organs* are concerned, still a profound homology remains throughout the whole animal series, viz. that of the *tissues*. Thus, in the lowest animals, a simple con-

tractile protoplasm is the homologue of the highly complicated muscular tissue of the higher animals, and the nerve-cells of the most minute ganglion represent those of the large cerebrum even of man. Moreover, in this point of view, as already mentioned, the simple gymnoplastic nucleated cell-like Gregarina may be regarded as homologous with a nucleated gymnoplast from the tissues of the higher animals or of man.

Still further, comparative physiology recognises homologies in vital actions. Homologous organs and tissues perform *homologous functions*, and possess homologous *vital properties.* The phenomena of nutrition and reproduction, and the property of contractility giving rise to motion, are manifested in, or possessed by, all animals; sensation and voluntary motion in most. Experimental physiology rests upon this fundamental unity of functions as well as of plan; and recognising the resemblances, whilst allowing for the differences, between man and the lower animals, it has succeeded in eliciting many important physiological facts and doctrines, which illustrate the functions of the human body, more especially, it may be added, those of the various parts of the nervous system.

Due consideration being given to all the preceding facts, to the small number of typical plans of animals, to their known modifications or variations, on the one hand, and to their mutual points of approximation or alliance on the other, and especially to the higher laws of homology and form,—a certain '*unity*' is seen to be manifested amidst all the '*variety*' which prevails; and more or less broken, yet *gradational*, lines can be traced through the animal series.

In conclusion, it may be remarked that the profound study of the entire chain of homologies connecting animals of the *same* type with each other, has led to the opinion of the existence of certain still more intimate relations between them, viz. those of a *genetic* kind, extending through vast periods of time, and expressed in the formula of continuous 'descent with modification.' The possibility of such genetic relations has even been surmised in regard to animals of the *different* types, and they have likewise been supposed to include man himself, considered as the highest existing animal form upon the earth.

RELATIONS OF MAN AND ANIMALS WITH PLANTS.—RELATIONS OF THE ANIMAL AND VEGETABLE KINGDOMS.

Besides the more intimate relations which exist between man and animals, and between animals themselves, there are other and highly important relations between the animal kingdom, man inclusive, and the vegetable kingdom; these relations are of three kinds, viz. of resemblance, difference, and dependence. To explain them, it is necessary to give some preliminary information concerning the vegetable kingdom.

Outlines of the Vegetable Kingdom.

Classification.—By Linnæus, plants were divided into the *Phanerogamia* or *Flowering* plants, and the *Cryptogamia* or *Flowerless* plants; but by Jussieu and the followers of the Natural system, a tripartite classification has been adopted into *Dicotyledonous*, *Monocotyledonous*, and *Acotyledonous* plants; the two former together corresponding with the Phanerogamia, and the latter with the Cryptogamia.

The Dicotyledona include the most highly developed forms in the vegetable world; they all produce true leaves, flowers, and seeds; they are so called because the seed possesses *two seed-lobes* or *cotyledons*, which, when developed in germination, form two little embryonic leaves. The stems of these plants are formed by the regular growth of new concentric layers of vascular and woody tissue deposited in succession one outside the other, the earliest formed layer immediately surrounding the central soft part called the pith, and the latest formed layer being that placed immediately beneath the cuticle or bark; hence the Dicotyledons are also named *Exogens*; their leaves present a branched and reticular arrangement of the so-called veins. The Dicotyledons include the great majority of the European flora, comprehending the timber, forest, and fruit trees, shrubs, and most of the firm-stemmed herbaceous plants.

The Monocotyledona also produce true leaves, flowers, and seeds; but, as their name implies, the seed has only *one seed-lobe* or *cotyledon*, which germinates into a single embryonic leaf. Their whole structure is simpler than that of the Dicotyledona. The vascular and woody tissue of their stems is not deposited in successive concentric layers; but is collected into numerous bundles, diffused or scattered through all parts of the cellular or pithy structure of the stem; hence these plants are also named *Endogens.* Their leaves are characterised by a parallel arrangement of the veins. The Monocotyledons are fewer in number than the Dicotyledons, and are rarer in Europe. Monocotyledonous trees, such as the bananas and the palms, are found only in hot countries. Most of these plants are herbaceous, such as the orchids, the irids, amaryllids, and lilies, the asparagus, colchicum and arum, the sedges and the extensive and varied family of grasses, including the bamboo, sugarcane, rice, maize, wheat, rye, barley, oats, and all the varieties of meadow-grass.

The *Acotyledona*, corresponding with the Cryptogamia, produce neither true leaves, flowers, nor seeds, and accordingly, as their name implies, have no seed-lobe or cotyledon. They are reproduced by much more simple structures, viz. single cells, often quite microscopic, named *spores.* In the larger kinds, a stem is developed, consisting of both vascular and cellular tissue, the former being in that case, either collected into a central mass, or into a few large regularly folded masses ; these are named the *vascular* Acotyledons ; they possess leaves or leaf-like parts, sometimes named *fronds.* In other and simpler kinds of Acotyledons, there is no vascular tissue, the entire plant being formed of cells, hence these are called *cellular* Acotyledons. The stem of the vascular Acotyledona and of one family of the cellular group, viz. the mosses, grows or increases only at the point or apex ; hence these have been named *Acrogens*; whilst the remaining cellular forms have neither stem, root, nor leaves, but consist of a fused mass of cells, called a *thallus*, and hence are named *Thallogens.* Amongst the vascular Acotyledons are found the lycopodiums, or club-mosses, some of which attain the height of trees ; the ferns, some of which, like the Cycas, also reach a great height and size ; and lastly the equisetums. To the cellular Acotyledons belong the mosses, the enormous family of fungi, including the large boletuses and agarics, the truffles and morells, and all the minute microscopic fungi, such as the Penicillium, Mycetum, Oidium, Botryllus, and others ; also the various lichens, and lastly the algæ or confervæ, some of which, such as the sea-weeds, are of gigantic dimensions, whilst some, like the Desmideæ, Diatomaceæ, Oscillatoriæ, Volvocinæ, Protococci, Monadinæ, and others, are quite microscopic ; many of these have been, from their manifestation of movement, erroneously classed with the infusorial animalcules. Amongst the fungoid group, the *Mycetozoa*, and, amongst the confervoid forms, the *Vibrionia*, occupy a doubtful position between the animal and the vegetable kingdoms.

Structure and Functions of Plants.—Plants, like animals, have a definite organisation and structure, and are endowed with special functions and properties, which are the subjects of study in vegetable anatomy and physiology. The characteristic functions of plants are those of nutrition and reproduction ; for in the few instances, to be hereafter mentioned, in which partial or general movements occur in them, such movements are involuntary and, when their purpose is evident, concur in one or other of the two proper vegetative functions. The chief nutritive organs in Exogens, Endogens, and Acrogens, are the *roots*, with their soft terminal absorbing points named *spongioles*, the *stem*, and its *branches*, and the *leaves* or *leafy fronds.* The roots, the proper organs of absorption, take up water holding in solution carbonic acid, ammonia, sulphates, phosphates, and other saline materials, constituting the ultimate food of plants. The stem and branches convey these materials, now somewhat enriched by substances already contained in the plant, upwards to all parts, in the form of the ascending sap. The leaves are the seats of the active elaborative vito-chemical processes of the plant : it is from their surface that the excess of water is exhaled by a process of *transpiration*, from little apertures or mouths named *stomates*, found especially on the under side of the leaf ; through these stomates, the leaves may also *absorb* vapour and gases. In the leaves, also, the

processes of *assimilation* are performed, as well as those of *respiration*, which in plants is rather an assimilative than a respiratory act, consisting essentially in the fixation of carbon, derived from carbonic acid, together with the elements of water and ammonia, and in the evolution of oxygen. These processes occur under the influence of solar light, and in this way, not only chlorophyll, the green colouring matter, but other ternary and quinary constituents are prepared, such as the vegetable acids, the carbhydrates, starch, sugar, gum, cellulose, and lignin or woody fibre, and also the hydrocarbons or fixed and volatile oils; and moreover by the fixation of nitrogen or ammonia, there are formed those most important albuminoid substances, gluten, fibrin or legumin, which are necessary to all the growing parts of plants, and which are stored up abundantly in the seed. The fluids returned from the leaves, supply materials, chiefly cellulose and lignin, for the formation of the new parts of the stem and roots, and so assist in building up the passive framework of the plant; and they also deposit in their path, by processes of secretion, special chemical compounds, such as the essential and fixed oils, and the vegetable alkaloids or bases, exemplified by quinine, morphia, thein, caffein, and asparagin; and finally even, it is said, throw off by an excretory process, chiefly by the roots, residual substances which would be injurious to the plant. The decomposition of carbonic acid, and the evolution of oxygen, which takes place in the mixed assimilative and respiratory functions of plants, are phenomena the reverse of those which occur in the respiration of animals, and by which oxygen is absorbed and carbonic acid given off. In the germination of the seed, and at the period of perfection of the flower, carbonic acid is, however, also given off by plants. In the absence of light all parts of plants are said to exhale carbonic acid, which must always exist in their fluids, and then escapes decomposition. In some plants, certain special fluids, more secretive than nutritive, constituting the so-called *latex*, circulate in peculiar vessels named laticiferous. The reproductive functions of all the phanerogamic plants are performed by the agency of the flowers, or rather by that of their most essential parts, viz. the *pollen* and the contents of the *ovule*, which are brought together by the various contrivances manifested in the structure and arrangement of the stamens, anthers, pistil, and carpels. The petals and sepals of the corolla and calyx, when present, are supporting, protective, ornamental, and attractive to insects, which aid in conveying the pollen to the stigma; bracts, stipules, and tendrils are also efficient organs of protection and support. *Buds* are the means of multiplication by division of the individual, seeds and spores by a true reproductive process. Within the fertilised ovule the *embryo*, with its one or two cotyledons, is formed. In the cryptogamic flowerless plants, instead of a seed containing an embryo, *sporangia*, or other organs, appear on the fronds or thallus, and produce within them the so-called *spores*. The nutritive processes of the cellular thallogens are accomplished without the aid of woody or vascular parts.

The vegetable textures of which all plants are built up, are the so-called *woody tissue*, fig. 47, *f*; the *vascular* or *tubular* tissue or *ducts*, *c*, *d*, *e*; and the *cellular* tissue, *a*, *b*. Certain parts, such as the pith, *a*, the cuticle, *b*, and the embryo of the higher plants, consist entirely of cellular tissue, i. e. of an assemblage of coherent vegetable cells. Even

the woody, *f*, and vascular, *c*, *d*, *e*, tissues are produced by various modifications and functions of such vegetable cells. As already mentioned, the thallogens are exclusively composed of such cells; and the very simplest forms of them, the lowest Algæ, consist but of a single cell, or are unicellular, fig. 46, *b*. The ovule of the highest plant, and the simple spore, are but different evolutions of this primitive vegetable cell.

Ultimately, therefore, all the vital functions performed by plants, viz. the so-called *vegetative functions*, whether *nutritive* or *reproductive*, are accomplished by the agency of cells. A vegetable cell, fig. 46, *c*, consists of the following parts:—*First*, the *cell-contents* or *endoplast*—a soft, usually colourless, fluid, slimy, or granular, mass, which always contains, when growing, some of the quinary nitrogenous, albuminoid matter or *protoplasm*, absolutely essential to all vital activity: the outer layer of this endoplast is rather firmer than the rest, and has been named the *primordial utricle*; within, or upon, the endoplast is fre-

Fig. 46.

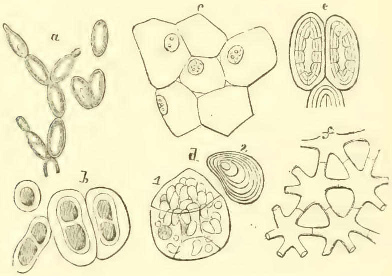


Fig. 46. Examples of vegetable cells (Schleiden, and others). *a*, conjoined and separate oval cells of the yeast plant, torula cerevisiæ; *b*, cells of an algaceous plant, hæmato-coccus binalis, single, double, and clustered in fours; *c*, polyhedral cells, with nuclei, nucleoli, clear contents, and distinct walls, from the onion; *d* 1, polyhedral cell from the potato, containing a nucleus, and many starch-grains, 2, a single starch grain more highly magnified, showing the concentric striæ; *e*, cells filled with concentric deposit of ligneous matter, from the gritty part of a pear; *f*, stellate cells, from the pith of the rush, showing the union of the different points of the cells, and the intercellular spaces. Moderately magnified.

quently found, at least in growing cells, *b*, *c*, *d*, a smaller vesicular body named the *nucleus*, having in its interior one or two *nucleoli*, and constituting apparently a special centre of activity or growth. The entire endoplast, thus described, is the essential part of every vegetable cell. Outside the endoplast, is the *second* elementary part, named the *cell-wall* or *periplast*, *c*, *d*, *e*, which is at first always thin, homogeneous, and transparent, and consists of the ternary cellulose tissue;

its office is evidently protective and supporting, but it permits of the passage of dissolved materials into and out of the endoplast which it surrounds—physical processes essential to nutrition and growth. The cell so constituted may alter in size and shape, may coalesce with other cells, fig. 47, *a*, may have its cell-wall perforated, *c*, or thickened by internal deposits, *d*, *e*, or its contents may be altered in the most diverse ways. Again, it may multiply itself by a gradual constriction and division of its endoplast, such division commonly affecting the nucleus also, and by simultaneous growth inwards of the periplast or cell-wall, so as to cut the primitive cell into two cells, each of which may again undergo a like process of subdivision, fig. 46, *b*. Grouped together in specially arranged forms and plans, more or less modified to suit various purposes, and held together by an intermediate cellulose uniting substance,—such cells, yet retaining their own independent powers, though co-operating with myriads of others—serve to build up even the highest plants, con-

Fig. 47.

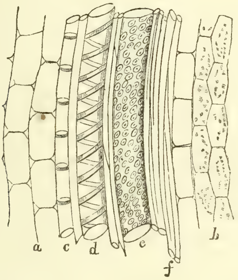


Fig. 47. Example of modifications of vegetable cells, forming the so-called vascular tissues of plants; from the Italian reed (Schleiden). *a*. elongated polyhedral cells of the pith; *b*, cells of the cuticle, containing granules of chlorophyll; *c*, annular vessel, formed by the union of cells, and absorption of their intermediate septa; *d*, spiral vessel, formed by union of cells, and deposit of ligneous matter in spiral lines; *e*, dotted vessel or duct, formed by another mode of ligneous deposit within coalesced cells. To the right of this are woody fibres, *f*, formed by solidification of fusiform cells with lignin. Moderately magnified.

stitute their organs, and perform their various functions, nutritive or reproductive. Or, one such cell, as in the unicellular microscopic Algæ, *b*, may embrace within its minute sphere of action, all the characteristic vegetative processes—absorption, elaboration and respiration, the growth of its own simple structure, and the reproduction, by division of its endoplast and periplast, of its own species,—thus evincing the close relationship of reproduction with nutrition, and the unity of all the so-called organic or organising processes. Unless in the case of the Mycetozoa,

it is not certain that any naked protoplasm, or gymnoplasts, exist in the vegetable kingdom.

Besides containing all the chemical elements found in animals (see p. 100), even fresh-water plants may have a certain quantity of iodine in their composition; whilst the marine algæ contain both iodine and bromine.

Resemblances between Animals and Plants.—Living animals and plants resemble each other in all the particulars which characterise bodies belonging to the organic kingdom of nature. They are both organised, i. e. composed of parts, *complex* or *elementary*, named organs, destined for special uses; or, in the simplest or lowest forms of both kingdoms, they consist of distinct structures, or tissues, manifesting vital properties, capable of being called forth by appropriate stimuli. In chemical composition, they likewise present a general resemblance, though it was formerly supposed that they were specially distinguished in this respect. Animals were known to contain proximate constituents, named quaternary, because supposed to consist of four elements—carbon, hydrogen, oxygen, and nitrogen—such as albumen and fibrin; while plants were said to contain substances of ternary composition only, i. e. consisting of carbon, hydrogen, and oxygen. But plants, as is now well known, also contain albuminoid substances, such as gluten, legumin, and others, which, indeed, constitute their most essential living parts; whilst the ternary compounds formed within them, viz. woody fibre or cellulose, starch, sugar, and oil, are merely the supporting portion of the vegetable fabric, or deposits in the general tissues of the plant. Moreover, starch, sugar, and even a peculiar form of cellulose, are found in the bodies of animals, the latter in the skin of certain of the Tunicata, starch and sugar, even in the highest animals and in man. As regards their vital properties and functions, animals and plants also resemble each other, especially in reference to the so-called vegetative functions, both nutritive and reproductive. Thus, both are nourished from without, by processes of absorption and interstitial assimilation; in both the functions of secretion, excretion, and respiration are observed; and a form of circulation is present in most animals and in some plants. In both the phenomena of growth take place; in both, existence is of limited duration; and, in both, the individual springs from a predecessor or parent, and in turn assists in reproducing new individuals or offspring.

Differences between Animals and Plants.—The distinction between animals and plants is easy, when attention is limited to the highest forms in each kingdom of organic nature; for no one can confound a tree with a quadruped. In general, the organs of animals are far more complex and numerous, and more specially devoted to particular purposes, than is the case in even the highest plants, the organs of which, as the leaves, are mere repetitions of the single leaf, or, as the sepals, petals, and even stamens, pistil, and parts of the fruit, are but modifications of the foliaceous organs. So also the tissues of animals are more numerous and more complex, and the animal functions more varied, than those of plants.

But at the lower end of the animal and vegetable series, the borders of the two kingdoms become, as it were, conterminous, and the difficulty of placing in their proper category some of the lowest organised forms, infusorial and algaceous, has perplexed both zoologists and botanists. Besides this practical embarrassment in regard to mere classification, there exists a real difficulty in determining, by means of sharp definitions, the differential characters between animals and plants generally. The following distinctions, however, are those usually drawn.

First, animals generally possess sensation, consciousness, and volition, whilst plants are certainly destitute of volition and consciousness, and also of true sensation; but there are a few animals which have no volition, as the Spongida, and some perhaps which have no sensation, as the Gregarinida; again, there are many plants, the movements of which are to some extent adapted to certain purposes, though they are not volitional, such as the climbing plants, the sunflowers, and others, which turn in obedience to light or other stimuli; and there are some, such as the sensitive plant, and the fly-catching plant, which possess a sort of excitability, suggestive of, though not attributable to, true sensibility in their leaves.

Secondly, motion, especially locomotion, is a great characteristic of animals; whilst plants, as a rule, are stationary. But there are certain animals which are fixed, such as the sessile Polyzoa, Cirrhopods, Actinozoa, Infusoria, and Spongida; and there are plants, such as the Centaurea and Berberis, which manifest a true contractility of tissue, and specific motions in their stamens; other plants, such as the Chara and Vallisneria, exhibit remarkable movements in the contents of their cells; whilst many of the forms among the minute

Algæ manifest active locomotion, such as the Volvox, Oscillatoria, Zygnema, and certain Monads. Whether such movements in plants, are due to other causes than contractility is not known; a proper contractile tissue is certainly more markedly developed in animals, existing even in the lowest forms, such as the Rhizopoda and Spongida.

Thirdly, there are certain differences between animals and plants, as regards their food, and its mode of preparation, before it is absorbed. Thus, animals being locomotive, usually seek their food, whilst plants, being fixed, find their food at the spot which they inhabit. But there are sessile or fixed animals, and, amongst the Algæ, moving plants. Animals usually feed periodically, or at certain intervals; but plants much more continuously. The food of animals is both solid and fluid, and the solid portions require to be dissolved by a digestive process, previously to being absorbed; the food of plants is always presented to them already in a state of solution. Animals, as a rule, receive their food into a mouth leading to a distinct stomach, or into some other internal permanent cavity, as in the Infusoria, or into a temporary cavity only, as in the Amœba and Actinophrys; whilst plants have no stomach or digestive cavity at all, but absorb their food directly at some part of their surface. But even this obvious distinction is not universal, the lowest Protozoa, viz. the Gregarinida, not possessing a stomach, or even a temporary digestive cavity.

The chief point of distinction between the food of animals and plants, relates to its source and chemical composition; and this constitutes a more positive ground of distinction between them. Animals require food already prepared by some pre-existing organism; that is to say, food composed of certain proximate constituents named organic substances, because they are the result of chemical combinations at present only known to occur in the living bodies of animals or plants. Animals, therefore, feed upon either animal or vegetable matter, i. e. on organic substances. But plants feed exclusively on inorganic substances, derived from the atmosphere, the water, and the soil. The chemical composition of the organic food of animals, for they too require air, water, and certain mineral constituents, is highly complex, consisting of the quinary substances known as albuminoid bodies, or their immediate derivatives, besides the carbhydrates, starch, and sugar, and the hydrocarbons, or fatty substances, all of which are reduced to a state of minute division, or solution, by

pecial digestive processes, and are then assimilated. These ubstances are obtained, in the case of carnivorous animals, rom other animals; in the case of the Herbivora, from plants; n the case of the Omnivora, from both sources; ultimately hey are always derived from the vegetable kingdom. On he other hand, the food of plants, in addition to the necessary aline mineral constituents, consists of carbonic acid, water, nd ammonia, which binary chemical compounds they, by id of their vito-chemical processes, stimulated by light and ieat, combine into the carbhydrates, to form starch, sugar, gum, and woody fibre, the hydro-carbonaceous oils, and the quaternary and quinary nitrogenous albuminoid bodies, such s thein, legumin and gluten. Plants, therefore, appear to iave the power of forming, as the highest product of their vital processes, from carbonic acid, water, ammonia, and sulphur, lbuminoid matter—a power not possessed by animals. Plants lso directly form the carbhydrates, and probably from these, he hydrocarbons; whilst if animals produce these bodies, it is upposed to be from the decomposition of albuminoid subtances. It has been noted that the organic acids and bases ormed in animals, are much fewer than those met with in plants, nd that but a small number are common to both kingdoms.

Lastly, the nature of the chemical processes which occur n the economy of animals and plants, must necessarily differ, n accordance with the difference in their respective food. In nimals, the organic constituents of the food once digested, bsorbed, and assimilated, undergo, under the influence of a certain temperature, many changes, the tendency of all of which may be expressed by the term *oxidation*, oxygen, derived rom without, being largely concerned in those changes, and the ultimate products being, when such changes are completed, chiefly water, carbonic acid, ammonia, and sulphates. The whole of these changes are *analytic*. In plants, the inorganic constituents of the food—water, carbonic acid, ammonia, and sulphates—once absorbed, also undergo, under the influence of ight, many changes; the characteristic of which is *deoxidation*, oxygen being given off in the process, which may be characterised as *synthetic*. Plants, therefore, build up from the dead or inorganic world, the organic materials of their own fabric, nd also those which alone can be converted into the substance of animals; whilst these latter restore to the inorganic world the chemical elements which have passed in succession hrough the living tissues of both plants and animals.

In this way, indeed, the balance between the two great subdivisions of the organic kingdom is maintained, and the continued existence of both insured. The germinating embryos, and the flowering parts of plants, however, give off carbonic acid; and so do all the parts of plants, during the absence of light; not, as may be suggested, in consequence of a process of oxidation, but because the carbonic acid, which then enters them as food, is no longer decomposed. It is also generally alleged that parasitic and other fungi absorb carbonic acid and give off oxygen, both during day and night; but, as regards the day-time, this is doubted by some.

In conclusion, the broad distinctions between animals and plants, consist in the possession, by the former, of true sensibility, consciousness, and volition; in the further possession of a stomach; in their inability to form albuminoid compounds, or other organic substances, directly from inorganic materials; and lastly, in their absorption of oxygen, and evolution of carbonic acid. On the other hand, plants are destitute of volition, consciousness, and true sensation; have no stomach; can form albuminoid and other organic compounds from inorganic matter; absorb and fix carbon, and give off oxygen. Lastly, it may be mentioned that, as a rule, animals, in accordance with their higher functions, possess not only more complex organs, but a much larger number of component tissues.

The form and structure of any microscopic organised body, will usually suffice to decide its proper position in the one or the other of the two organic kingdoms of nature, provided only that it be in its fully developed condition; but in regard to germs, whether ova or spores, it is difficult, and sometimes impossible, to arrive at a conclusion.

RELATIONS OF THE ORGANIC WITH THE INORGANIC KINGDOM OF NATURE, OR OF ANIMALS AND PLANTS WITH MINERALS.

Plants, and animals, including man, which compose the organic world, are distinguished from the inorganic world by their manifestation of 'life.' The Linnæan definition 'Lapides crescunt, Vegetabilia crescunt et vivunt, Animalia crescunt, vivunt et sentiunt,' i.e. 'Stones grow, Plants grow and live, Animals grow, live, and feel,' also expresses, though imperfectly, the distinctions between the organic and inorganic kingdoms of nature; for mineral substances simply increase

or grow by *accretion*, plants and animals grow by means of *living* processes, whilst animals surpass plants by possessing *sensibility*. A closer inspection of the characters of organic and inorganic bodies reveals, however, a series of important differences, not only in their form and size, but more especially in their chemical characters, their structure, the nature of the actions which take place within them, their mode of formation, maintenance and increase, their duration, and their manner of production, or reproduction.

The *form* of organic bodies is always determinate; that of some inorganic bodies, such as crystals, is likewise determinate, but this is not an essential characteristic, the greater number of them being irregular in form. Organic bodies do not present strictly geometrical forms, and have more or less curved outlines and surfaces; whilst, as a rule, inorganic bodies, when of determinate shape, have geometrical forms, plane surfaces, and straight outlines; but there are a few exceptions of crystals having curved surfaces, viz. the diamond, dolomite, and spathic iron; and inanimate matter sometimes presents a tendency to assume a more or less spheroidal shape. The simplest forms of organic bodies present a universal tendency to a spheroidal, oval, or ovoid shape; but linear forms prevail in the more highly developed species; ramification and repetition of parts are common, and very frequently spiral forms are seen, either in parts or in entire organisms. A bilateral symmetry is likewise almost always apparent; though this also is met with in the inorganic crystalline bodies. The irregularly formed inorganic bodies have irregular surfaces, and are without symmetry.

In *size*, organic bodies are determinate, each species within certain dimensions. Inorganic bodies having crystalline forms, are also limited in size, but they exhibit wider individual deviations in this respect; whilst the non-crystalline inorganic bodies have no determinate bulk.

Organic bodies contain no *chemical elements* beyond those which are found in the inorganic world; but the total number of elements contained in all the organic compounds, is fewer than that of those contained in the mineral kingdom. Organic bodies present a striking uniformity of composition; most of them being ternary, consisting of carbon, hydrogen, and oxygen; a certain number quaternary, containing, in addition, nitrogen; and a few only, absolutely essential to organisation, quinary, containing likewise sulphur or iron. Inorganic bodies, on the

other hand, exhibit a far greater variety in their component elements; they also present a greater variety in their atomic constitution, being not only ternary, quaternary, or quinary, but frequently binary or simple.

The compound chemical substances contained in or derived from organised bodies, are named *organic* compounds, and are treated of in so-called *Organic Chemistry.* Their chemical constitution is more complex than that of inorganic substances, and their properties are more various. Though composed of but a few elements—chiefly, as already stated, of these four, carbon, hydrogen, oxygen, and nitrogen—they are characterised by the *high number of atoms* of those elements, which enter into their composition; so that e. g. whilst only one atom of carbon, or two of hydrogen, are combined with oxygen to form carbonic acid and water, no less than six atoms of carbon, twelve of hydrogen, and six of oxygen, enter into the formation of grape sugar. The *molecules* of organic substances, i. e. the aggregate of all the atoms of each element which they contain, are therefore *larger* than the molecules of inorganic chemical compounds. In both organic and inorganic chemistry, certain *radicals* are supposed to enter into combination in fixed proportions, with some single element, such as oxygen, chlorine, or even a metal. In organic chemistry, such radicals are always *compound*, consisting themselves of two elements, as for example, cyanogen, which is a compound radical containing carbon and nitrogen; but such compound radicals also exist amongst inorganic bodies, as e. g. cyanogen itself when made synthetically from inorganic matter, and also ammonium, which is composed of hydrogen and nitrogen. Until comparatively recent times, a broad distinction was supposed to exist between all organic chemical compounds, or the substances immediately derived from their decomposition, and purely inorganic chemical substances, the former being believed to be alone producible by vital actions. But the distinction has, in regard to many substances at least, been completely effaced by the discoveries of Wöhler, and more especially by the labours of Berthelot and others. The former chemist first showed that urea is identical with cyanate of ammonia, which can be artificially produced, and hence is named artificial urea. Ammonia, formerly supposed to be producible only from the decomposition of previously organised matter, can now be obtained from inorganic materials, by first making carbon and nitrogen unite artificially, under the in-

fluence of carbonate of potash, to form cyanogen (in cyanide of potassium), which, decomposing with water, yields ammonia. Again, tartaric and oxalic, and some other organic acids, and even alcohol, have been made artificially by a series of synthetic steps, without the intervention of any vital process, or the employment of any organic substance, or the product of any previous vital action. Thus, acetylene (C_2H_2) is formed by electric sparks passed from carbon points through hydrogen gas; this acetylene is made to combine with copper, and then, when subjected further to the action of nascent hydrogen, produces ethylene (C_2H_4); the ethylene, united with sulphuric acid, forms a compound ($C_2H_4SO_4$), which, when diluted with water and distilled, gives off alcohol (C_2H_6O). It would therefore seem possible that other and higher so-called organic compounds, such as sugar, quinine, and even albumen, may hereafter be artificially produced from inorganic materials only. These researches already suffice to show that the *synthetic* actions, by which plants build up organic substances from inorganic elements, are similar in nature to those which have been devised by man; and that, accordingly, the chemical molecular attractions employed or operating in each, are identical. So also, the *analytic* or decomposing processes of the chemist, are paralleled in the laboratory of the living organic world; for sugar in solution, at certain temperatures, under the influence of the yeast fungus, *Torula cerevisiæ* (supposed to be one form of the *Penicillium glaucum*), produces alcohol; at lower temperatures, under the action of the vinegar plant, Mother, or *Mycoderma aceti* (said to be another form of *Penicillium glaucum*), it yields acetic acid; and in the presence of *Oidium lactis* (likewise referred by some to the same fungus), lactic acid. These facts, moreover, furnish proof of the identity of the chemical force acting in the organic world, and that which is artificially set in operation by man.

Furthermore, organic bodies, with the large number of their atoms, and their complex molecular constitution, are extremely liable to *decomposition*, as exhibited in various ways; thus they are, for the most part, unstable or prone to putrefaction, though it must be admitted that there are likewise inorganic compounds of most unstable character. The action of heat on organic compounds is invariably completely destructive, their elements being resolved into other and simpler compounds, such as the products of destructive distillation or decomposition, which, on the withdrawal of heat, do not reunite to form the

original complex organic substance; wood, e. g. gives, by distillation, tar, methylic alcohol, benzole, acetone, acetic acid, and certain gaseous substances; and, if completely burnt, yields carbonic acid and water, which substances do not reunite to form wood. Most inorganic bodies are comparatively stable, and do not undergo putrefaction; moreover, though always changed in condition, and frequently decomposed, when subjected to the action of elevated temperatures, they may, and often do, relapse into their original state when the temperature is again lowered.

Organic bodies are still further, and more distinctly, characterised by their *structure*, which is always heterogeneous. Thus, organic bodies are composed of different parts named organs and tissues, each bearing a certain relation to the rest, having peculiar uses, and consisting of a mixture of solid, fluid, and even gaseous materials, and not exclusively of one or other condition or kind of matter; the solids serve to support and hold together the organs or tissues, and to contain the fluid parts; whilst the fluid parts, which hold the gases in solution, are necessary for the diffusion of nutritive materials amongst the solids. The organs and tissues themselves are not homogeneous, but also consist of organic structural elements, frequently of the so-called, vesicular, or naked, nucleated cells, and other parts, exhibiting minute but regular and definite details of structure, the whole being usually enclosed in a general investment. The simplest animals and plants, and the animal germs and vegetable spores, likewise exhibit such definite structure, consisting, as we have seen, either of cystoplasts or gymnoplasts, i. e. of vesicular or naked nucleated cells. Even simple nuclei, and the primitive protoplasm, consist of elementary granules.

It is necessary to admit that this definite cell structure, which is the characteristic of obvious 'organisation,' and perhaps also the formation of protoplasmic nuclei and granules, are not merely necessary conditions of 'life' or 'vital action,' but are themselves products of such action, assimilative and formative, metabolic and metamorphic. Without such organic vital action, perhaps the development of organisable substance is not conceivable, certainly not that of organised structure; and hence it is, that the mind is driven to the assumption or inference that some peculiar force, superadded to the inorganic forces of nature, is here in action. Now, inorganic bodies have no such structure; not even a crystal exhibits it when examined

by the eye or by the microscope; its substance, even to the minutest molecule, is homogeneous, although a few examples occur of crystallised bodies, such as ice, having minute drops of fluid or gaseous matter confined in little chasms in their interior. But inorganic bodies, generally, are composed either of solid, liquid, or aëriform matter, the particles of which are simply held together, or are intermingled.

The heterogeneous composition or structure of organic bodies, as compared with the homogeneous substance of the molecules of inorganic bodies of the most regular form, such as crystals, is connected with the tendency and necessity of the former, during their life, to undergo ceaseless *internal motion*, and constant *change*; whilst the latter, when once formed, may remain unchanged for an indefinite period of time. The inmost substance of an organic body continually suffers those changes—changes of absorption and assimilation of new material, and removal of old material—which constitutes the very essence of vital action; whilst the material of an inorganic body, so long as it preserves its individuality, continues unaltered. An organic body is nourished and grows; an inorganic body merely increases in size. The nutrition and growth of an organic body, are accomplished by an interstitial process of waste and repair, and by evolution of new elementary parts, both processes depending upon a deposit and accretion of new selected material around or within each elementary constituent of its organised structure, or, as it has been said, by intussusception; whilst, on the other hand, the inorganic body, whether crystalline or non-crystalline, simply increases by the juxtaposition or superaddition of like matter upon its surface, i. e. by an accretion to its general or external surface only.

Organic bodies possess, in their perfect condition, powers which are only called into activity by stimuli, under the influence of which they react, as in the case of the germ, or seed. These powers do not last indefinitely; but they may remain dormant for a long period, even for thousands of years, in the case of seeds, without being extinguished. Inorganic bodies retain their own properties, however, for indefinite periods.

Organic bodies, manifesting life, are subject to the conditions of health and disease. Moreover, their *duration* is limited; the individual animal or plant, however complex, or however simple, ultimately dies; whilst inorganic bodies either remain unchanged, enduring indefinitely, or, if they undergo decom-

position, it is in order that their elements may assume conditions of more perfect stability.

To maintain the continued presence, on the earth, of organic bodies, which, subject, as they are to individual death, have a limited duration, the *reproduction* of the species is provided for. Hence the last characteristic of organic bodies, as compared with inorganic, is this: that they are all derived from previously existing parents or stocks, by ova, germs, gemmules, buds, seeds, or spores. Spontaneous generation, which will be hereafter discussed, has not yet been proved to occur in regard to any organic body, animal or vegetable. Organic bodies go through a cycle of changes, both of form and composition. They are nourished, grow, and are continually changing their substance and shape; they attain perfection, give rise to new individuals like themselves, and then die. No such cycle of change and reproduction is observed in regard to any inorganic body.

SPECIAL PHYSIOLOGY.

THE ANIMAL FUNCTIONS.

These, as already explained, are Motion; Sensation, common and special; the Regulation of Movement; and the higher Psychical functions.

MOTION.

All power of intrinsic self-movement, or spontaneous action, in man and animals, depends either on muscular contractility, that particular form of contractility possessed by a specially organised tissue, the muscular tissue, on the so-called ciliary motion exhibited by the minute vibrating organs called cilia, or on the less common and obvious actions of contractile sarcodous cells, or still simpler masses of protoplasm. General movements are impressed on living animal bodies, as well as on dead ones, by the force of gravitation, and these movements enter, as it were, into their various locomotive or other acts, especially in progression, whether this be terrestrial, aquatic, or aërial. Gravitation also influences the special movements of the limbs and other parts of the living body.

The physical force resulting from the recoil of the yellow elastic tissue, which is so frequently employed in the animal economy, likewise assists in the intrinsic movements of many parts; but this tissue cannot properly be regarded as an original source of motion, for it must first be extended, before it can act, and this extension is accomplished, either by gravity or by muscular effort.

There likewise occur in certain fluids and tissues of the body, when examined under the microscope, movements of a tremulous character, named *molecular movements*, as in the fine particles or molecular basis of the chyle, in pigment granules suspended in fluid, or in these or other minute granules contained in the interior of cells. These movements are purely

physical, and may be observed with the microscope, in any very minute particles of dead matter sufficiently light to float in a fluid.

Still more recondite molar and molecular movements, of a physical and chemical kind, occur in the transference of dissolved material by osmosis and dialysis through the body; in the transmission of sensory and motor impressions along the nervous substance; in the passage of electrical currents through the tissues; and, lastly, in the intimate and incessant changes of nutrition. These movements, thus grouped together, are vito-chemical or vito-physical; and belong to a class in which perhaps, hereafter, even muscular, ciliary, sarcodic and protoplasmic movements will find their place and affinities.

MUSCULAR CONTRACTILITY.

Contractility, speaking generally, is, as we have seen, that property by which a living tissue is capable of shrinking in certain directions, so as to undergo a spontaneous change of form. The muscular *contractility*, muscular *irritability*, *vis musculosa*, or *vis insita*, is possessed by all the forms of muscular tissue, viz. the striped muscular fibre, the plain or unstriped fibre, and the contractile fibre-cells. This most important vital property, when called into play, produces *muscular contraction*, which does not consist of a shrinking, condensation, or contraction of the tissue, in all directions, such as is undergone by a mass of iron in cooling, but of an approximation of the particles in some definite direction; viz. in that of the length of the fibre, or fibre-cells. Hence the fibre, or fibre-cell, whilst it shortens itself, always increases in thickness.

Contractility is distinguished from mere elasticity, by the fact that it is a property of a living tissue only, i. e. a vital property; whilst elasticity is a physical property, which persists in a tissue after death, until decomposition or desiccation destroys it. Moreover, elasticity merely requires, for its exercise, that the elastic part should be previously extended; whereas contractility demands the agency of some external exciting cause or influence, which is called a *stimulus*. Hence the term muscular *excitability*, occasionally used.

The *stimuli* capable of exciting the property of muscular contractility are very various. Some are mechanical, such as a weight, a blow, or a scratch with a pointed instrument, or even

a sharp knock on a muscle in the living body; heat or cold, especially sudden changes of temperature, also act as stimuli; the chemical stimuli are acids, alkalies, or mineral salts; vegetable irritants also act, such as mustard; electrical stimuli, such as the galvanic current, and electrical shocks; and, lastly, the vital stimuli, originating in, or acting through, the nervous system, such as the reflex, emotional, ideational, and volitional stimuli. It is by means of these vital stimuli that the muscular tissues are most frequently excited to contract in the living body.

These stimuli may be applied either directly to the muscles, or indirectly through the nerves; thus, when the prepared hind-limb of a frog is so removed from the body, that a portion of the sciatic nerve, in an uninjured state, projects from its upper end, a mechanical, chemical, or electrical stimulus may be applied either directly to the muscles, and will make them contract, or they may be applied indirectly to the projecting nerve, with the same, and even with more striking effect, so long as the nerve retains its own vital properties. In the former case the contraction is named *idio-muscular*; in the latter, *neuro-muscular*. The nerve itself is said to conduct the stimulus to the muscle; but, as we shall hereafter see, the nerve is probably excited by the stimulus, a certain change takes place in it, and this change is propagated along the nerve. Even in the so-called direct stimulation of a muscle, the nerves contained within it may be concerned, so as to constitute that also a case of indirect stimulation.

Certain chemical stimuli, such as alkaline solutions, act equally well, if applied either to the muscle or to the nerve; some, such as alcohol, creosote, and lactic acid, act almost solely through the nerves; whilst others, as sulphate of copper and ammonia, operate powerfully and almost exclusively on the muscle, but hardly at all through the nerve. Over-stimulation as, for example, repeated electrical and powerful discharges, temporarily destroys the contractility. So likewise portions of muscle subjected to extreme weight lose their contractility. Moderate, but numerous and rapid, electric shocks produce a state of continuous contraction, known as *tetanus*; in the frog, at least 15 shocks per second are necessary to tetanise the muscles; with about 100 shocks per second the tetanus ceases, but it is again induced by increasing the strength of the current. A uniform continuous current does not maintain the original amount of contraction, the muscle gradually lengthening again

somewhat. A muscle exhausted by long continued stimulation, recovers its contractility after sufficient rest; this is also true of muscles recently separated from the body. But in atrophied muscles, in which the transverse striæ are destroyed, and the whole fibre filled with fat particles (fatty degeneration), there is no contractile power remaining.

The phenomena which characterise muscular contraction, have been chiefly studied in the striped muscular fibres of animal life. The act of contraction usually begins at either end of a fibre, but often at one or more intermediate spots. When a single fibre undergoes contraction, a slightly darker spot first appears at some point of its border; this spreads across the whole diameter of the muscle, and, on careful examination, it is seen that the transverse striæ become finer, and are drawn closer together, becoming twice or even four times as close as in the relaxed fibre; this action, the limits of which are well defined, then continues to spread each way through the fibre, by a wave-like progression, parts of the fibre becoming contracted, whilst other parts are assuming a relaxed form. The changes thus described, and the accompanying approximation of the transverse striæ, appear to be due to a corresponding shortening of all the component fibrils of a single fibre, and the general result is a shortening of the whole fibre, which, at the same time, becomes thicker in its contracting portions. Supposing the ends of the fibre to be free, it still continues soft and flexible; but when muscular fibres, as in a perfect muscle, are attached at their two ends, then their substance becomes firm and hard, as may be felt during the contraction of a living muscle in the arm. This increased firmness is due to increased tension of the fibres, and does not imply, as might at first be supposed, any important condensation of the muscular substance; for experiments show that this is very slight, if it occurs at all. Thus, the arm of a man has been enclosed in a glass cylinder having a narrow upright glass tube connected with it, the part of the cylinder not occupied by the arm being filled with water (Glisson); again, the prepared hind-limb or limbs of frogs, have been suspended in a bottle of water, provided with an upright capillary tube connected with its neck (Sharpey, Weber, Valentin, and others). The muscles of the arm have been then brought into play, or, the muscles of the frog's limbs have been excited to contract by electrical currents passed into them along wires properly fixed for that purpose; and any change in their

bulk, indicated by a fall in the level of the water in the upright tubes, has been noted. By most observers (Prevost, Dumas, Matteuci, Sharpey) it is stated that no diminution of bulk occurs under such circumstances, but according to Ermann, Weber, and Valentin, a diminution, scarcely perceptible in careful experiments, amounting only to from $\frac{1}{13000}$ to $\frac{1}{10000}$ of the bulk of the contracting muscles, takes place.

When a muscular fibre relaxes, it resumes its previous length, and at the same time diminishes in thickness; and if its points of attachment remain stationary, or at the same distance from each other, the fibre is thrown necessarily into zigzag flexions, specially noticed by Prevost and Dumas, and at first erroneously supposed to be produced in the *active* state of the muscle, and to account for its shortening. During contraction, the sarcolemma of each fibre is passive, and is either thrown into minute folds, or else displays a feeble elasticity. The contractile property, indeed, resides entirely in the sarcode, or peculiar fibrillar contents of the tube of the sarcolemma.

According to Helmholz, the contraction of a muscle is not instantaneous, but a certain interval of time, about $\frac{1}{100}$th to $\frac{1}{50}$th of a second, elapses between its stimulation by electricity, and its actual contraction; this he names the period of *latent contraction*, or *excitation*. The muscle at first contracts quickly, then more slowly; and it takes a longer time when powerful contractions are excited. The *velocity* of the wave of contraction, in the frog's muscle, is about forty inches per second (Aby). The rate of motion along any particular muscular fibre is such, therefore, that its contraction may be regarded as almost simultaneous from one end to the other. But there is reason to suppose that in any given muscle, certain fibres are undergoing contraction whilst others are at rest, an alternation of labour which would enable a muscle to maintain a longer effort with less exhaustion or fatigue.

The amount of contraction which occurs in a detached frog's muscle is, according to Weber, from 50 to 60, or even 80 per cent. of its length; that is to say, the muscle shortens to one-half, or even to one-fifth, of its length. In the living animal and man, owing to the resistance of antagonistic muscles, and to the structure of the joints, the muscles shorten themselves only about one-third of their length.

In the frog's muscle, the maximum amount of shortening takes place when the contraction is sudden, when the muscles

are not fatigued by previous stimulation, and when the resistance offered by weights appended to them is slight.

The striped and unstriped muscular fibres present certain *peculiarities* in their action, and so do the muscles of the heart. Thus, when the heart is artificially excited at any one point, a rapid and powerful contraction of a large part of its walls ensues, quickly followed by relaxation, and then by a succession of contractions and relaxations. When similarly excited, the unstriped muscular tissue of the intestines contracts more slowly, but more permanently. In non-striated muscles generally, the contractions induced by electrical discharges are partial or local, slowly induced, sometimes interrupted, and last after the stimulus is removed; but, in the striated muscles, rigid, general contractions quickly occur, continue so long as the stimulus is applied, and cease suddenly on its withdrawal. Contractions induced indirectly through the nerve-trunks, are more sudden, general, and energetic, than those occasioned by direct stimulation of the muscle. Some involuntary muscular fibres are more easily and powerfully excited than others, as, for example, those of the intestines, as compared with those of the gall bladder and the ureters, even cold air being sufficient to induce contractions in them. The peculiarities now described, are manifested also in the ordinary actions of the different kinds of muscular tissue during life. Thus the voluntary striped muscular tissues act suddenly, powerfully, and in effective combination, whilst the plain involuntary muscles contract much more slowly, partially, and feebly; as witness the quick, general, and energetic movements of the limbs, fingers, tongue, and eyelids, as compared with the slower, more local, and weaker movements of the muscular coat of the stomach and intestines. In the latter organs, the degree of contraction is likewise about one-third. The contraction also presents a great peculiarity, viz. that of being propagated onwards, or travelling along successive portions of the alimentary canal, by what is called *vermicular* or *peristaltic* action. It is, moreover, in these and other cases, excited by the contents of the muscular canals. In the heart of man and the higher animals, the imperfectly striated muscle, probably from some peculiarity of its nerves, contracts repeatedly, in regular and continuous order, alternating with certain periods of repose: this is called *rhythmic* contraction. It is observed also in the lymphatic hearts of the frog, and in the hearts or dorsal vessels of the lower animals.

The *force* with which a voluntary muscle contracts, is very great, much greater than the mechanical resistance offered by a dead muscle. It is equal to the lifting, through a minute distance, of a mass sixteen to seventeen thousand times its own weight; but as the distance is increased, the weight lifted is diminished. This force is exerted more favourably at the commencement of contraction, and gradually diminishes to zero, as the muscle shortens to its extreme degree. The *amount of force* depends on the *number* of the contracting fibres, whilst the *degree of shortening* depends on the *length* of those fibres.

In order that a muscle should act properly, its temperature must be at a due elevation, its supply of blood must be sufficient in quantity and of proper quality, and its nutrition amply provided for in the intervals of contraction. Arterial blood is essential to the healthy maintenance of muscular contractility. If the muscles be subjected to excessive heat, or be exposed to extreme cold, they will be in the former case exhausted, and in the latter benumbed. If the artery supplying a muscle, or set of muscles, be tied, their contractile power is destroyed; and if the blood be venous, or charged with carbonic acid, it will impair or destroy their irritability.

When a muscle ceases to act, it relaxes, or again elongates more or less, according to the position of the bones to which its ends are attached; and muscles evidently possess a certain amount of *flexibility* and *elasticity*, or *resilient power*, to adapt them to the changing positions of the limbs at the joints, and to the various conditions of length rendered necessary by those changes, even when the muscular fibres are in a state of inaction. The elasticity of muscular tissue is, however, very slight, and it diminishes during contraction. It would seem to be much greater, but much less perfect in its action, in the dead than in the living muscle. Thus, a dead muscle requires a greater force to stretch it, but, unlike a living muscle, does not return to its original length when the force is removed. A living portion of muscle undergoes an extension or elongation, when a certain weight is appended to it; the amount of elongation with moderate weights, is proportioned to the weight, but, with greater weights, the effect is no longer proportional; in dead muscle, and also in paralysed muscles, the relative elongation is less. The physical cohesive power, or absolute strength of muscular tissue, increases up to the adult condition, and then diminishes. It is said

to be greater during the so-called rigor mortis, but it decreases some time after death, when the muscles tear more easily.

After a muscle has contracted a certain number of times, a sense of fatigue or exhaustion is experienced in it,—a sensation which must be transmitted to the sensorium through the special sensory nerves of the muscle. It is these nerves also which must convey to the mind accurate information concerning the condition of the muscle, and the amount of effort which it puts forth in any particular action. It is also by these nerves that the impressions which cause the sense of pain in cramps, or other morbid conditions of muscle, are conveyed to the brain. That kind of sensation, which informs us of the amount of action in a muscle, is called the *muscular sense* ; it is by this that we judge of different weights, and are able to maintain continued muscular effort. The other muscular sensations are probably only modifications of this sense.

When a muscle is quite fatigued, it requires rest or repose for the recovery of its exhausted irritability. Excessive exercise of a muscle, with due intermediate intervals of rest, increases, not only its contractile power and facility of action, but also tends sooner or later to an over-nutrition and increased development of its bulk, or *hypertrophy*, probably, as is supposed, from an increase in the size of its individual fibres, and not by the addition of new ones. If, on the other hand, a muscle be not sufficiently exercised, it falls into a state of *atrophy*, or wasting, or even undergoes a fatty change in its fibres, the striæ of which disappear; in either case, its contractile force is diminished and ultimately lost. The same changes and loss of irritability take place in chronic paralysis. There is a particular condition or state of slight tension of healthy muscles, which, beyond their mere elasticity, accounts for their retraction when they are cut across, and which is named their *tonicity*, or *tonic state.* It is persistent only so long as they are healthy, and remain in connection with the nerves and nervous centres; for if the nerves are cut, or if the nervous centres in connection with them are destroyed, the muscles lose their tone and become flaccid. It is this property continually in action, which serves, more than the elasticity already alluded to, to keep antagonistic muscles in a due state of equilibrium, in varying positions of the limb; it seems also to be by a powerfully-exercised tonicity that sphincter muscles, like that placed around the outlet of the alimentary canal, are kept contracted.

The muscular contractility is not extinguished immediately after death, but is retained for different periods by different muscles, and in different animals. For example, in the cold-blooded vertebrata, the reptiles, frogs, and fishes, it may last for many hours, or even for days; a turtle's heart has been known to beat three days after the death of the animal. In warm-blooded vertebrata, man, quadrupeds, and birds, the irritability ceases a few hours after death, soonest of all in birds.. The irritability lasts longer in animals just born, and in hybernating animals killed in the winter during their sleep. The more active the respiration, the more active the muscular irritability; but the more dependent also is this irritability upon the respiratory process, and hence its speedier extinction in animals the respiration of which is active, and its longer duration in those the respiratory changes of which are of a feebler character. In the human body, the irritability lasts longer in certain muscular parts than in others; it disappears first, in the left ventricle of the heart, then, in succession, in the intestines, stomach, urinary bladder, and right ventricle of the heart, in all which parts it is lost before the expiration of an hour. It afterwards expires in the voluntary muscles, first in the trunk, then in the lower limbs, and lastly in the upper limbs. It continues still later in the left auricle, and latest of all in the right auricle of the heart, the *ultimum moriens* of Galen. It is totally lost within seventeen hours after death. The contractility is said to be destroyed, sometimes immediately, in cases of death by lightning, or by violent injuries to the nervous centres. It disappears early in cases of poisoning by carbonic acid gas, or sulphuretted hydrogen. Cold air or water, and narcotic agents, taken internally, are said to hasten its departure. Narcotic solutions, morphia, cyanide and other salts of potassium, and the upas poison injected into the blood, also lessen or destroy it, and much more rapidly and effectively when directly applied to the muscles, though not necessarily when applied only to the nerves. Immersed in sulphurous acid, hydrogen, carbonic oxide, and carbonic acid gases, the muscles lose their contractility partly or entirely. Venous blood, which contains much carbonic acid, acts as a poison, lessening their irritability; whilst oxygen and arterial blood preserve it, and the latter, defibrinated and injected into a limb recently dead, will even restore the irritability after it has been suspended. Contractility, as already stated, is wholly lost in atrophied muscle.

Phenomena accompanying Muscular Contraction.

Certain important phenomena accompany those changes of form and condition in the muscles, which constitute their so-called contraction. In the first place, there is a sound produced by the contraction of muscles, which may be easily heard by placing one finger so as to close the ear, resting the elbow upon a table, and then contracting the muscles of the fore-arm. This sound has been well compared to the rumbling noise of distant carriages, and is called the *muscular sound*; it is probably owing to the friction of the contracting fibres against each other; its vibrations are said to be from thirty-two to thirty-six per second.

Another phenomenon accompanying muscular contraction is the *production of heat*. The fact may be shown by direct experiments with the thermometer; but the exact amount of elevation of temperature can be more accurately measured by means of a thermo-electric apparatus, of which the contracting muscle forms a part.

If a metal ring be made of a semicircle of copper wire, and of another of iron wire, soldered together at their ends, and if one of the points of junction be made hotter or colder than the other, then thermo-electric currents, i.e. currents of electricity developed by heat, are produced in the compound metallic ring. By introducing a needle galvanometer in the circuit of the ring, the *direction* and *force* of such currents can be measured for each *degree* of *unequal temperature* in the two points of junction.

A needle galvanometer consists of a magnetised needle, suspended horizontally by a single fibre of silk, and placed *under cover of glass*, means being provided for passing a current of electricity in its neighbourhood at will. A circular card or disk, marked with degrees, and fixed beneath the needle, accurately registers any movement which takes place in the latter.

Now, when a current of electricity is made to pass, in any definite direction, near such a magnetised needle, the latter is deflected, or turned to one side or the other; the wire through which the electrical current passes, itself acts like a magnet, and tends, by virtue of mutual attractions and repulsions, to cause the needle to stand at right angles to it. The direction of the deflection depends on the direction of the current, and the amount of deflection on the force of the current. If the observer looks down upon a galvanometer, with the north pole of the magnetised needle turned from him, and a current of electricity be passed along a neighbouring wire, *above* the needle, also in a direction *from* him, the needle will deviate to the left hand; but if the current were passing *under* the needle in the same direction, the needle would deviate to the right hand. If the current passes *towards* the observer *above* the needle, the needle is deflected to the right, and if *below* it, to

the left. Now it is obvious that if the wire, along which the current is made to pass, be bent into an oblong horizontal loop, within which the needle is suspended, so that the current passes *from the spectator above the needle,* and returns *towards him under it,* the force, which causes the needle to deflect towards the left hand, is doubled; because the departing current above the needle, and the returning current below it, have both a tendency to make the needle deflect in the same direction, i. e. to the left. By covering, and so insulating the wire, and by multiplying its departing and returning bends, by coiling it up an immense number of times into the required oblong loop, within which the needle may be suspended, the deflecting force is still more powerfully increased; and in this way, with a coil of very fine wire, many thousands of yards, nay, even some miles in length, exceedingly feeble electrical currents can be detected, from their causing the deflection of a delicate and lightly-suspended magnetised needle. Such a needle, however, suspended singly, is subject to the magnetism of the earth, which would derange, or arrest, the operation of very feeble currents. Hence, to prevent this, another needle, of equal magnetic power, is suspended below the upper one, and attached to it by a rigid axis, having, however, its poles turned in the opposite directions, the north pole of one being under the south pole of the other, and vice versâ. In this way, the effects of terrestrial magnetism are neutralised, and the needle is made *astatic* and ready to be impressed solely by such currents as may pass through the coil of wire within which it is suspended. Such an instrument is influenced by electrical currents of every kind, whether developed by friction, thermal influences, chemical, or vito-chemical action; the force of the current is always measurable in degrees upon the scale.

In order to apply the thermo-electric test to the measurement of heat developed in a living animal or man, a U-shaped piece of wire, composed half of iron and half of copper, joined together at the bend, is immersed in water of a *known temperature.* A needle, also half of iron and half of copper, is thrust through the tissues, and so adjusted that the point of junction lies in the part, the relative temperature of which has to be determined. The iron shank of the U-shaped wire is now connected with the iron end of the needle, and the copper shank of that wire with the copper end of the needle; but somewhere in the last-named connection the galvanometer is inserted. Any difference in temperature between the metallic junction immersed in the water, and that embedded in the living tissue to be examined, creates a current, either one way or the other, according to which junction is hotter than the other; and any elevation or fall of temperature in the one, such as might be produced by the acts of contraction and relaxation of a muscle, would cause proportionate, and measurable, changes in the strength of the electric current.

As thus determined, the quantity of heat evolved in contracting muscle in warm-blooded animals, has been found sufficient to raise its temperature by 1° or 2°; in the frog the elevation of temperature is rather less than $\frac{1}{5}$°. This effect may be partly due to friction, but it is supposed to be chiefly owing to chemical combinations taking place in the muscle,

incidental and essential to the act of contraction. Probably these chemical changes consist in an oxidation of the constituents of the muscular tissue; for exhausted muscle contains more creatin, creatinin, urea, and inosinic acid, than muscle in a state of rest (Helmholz); the substance of quiescent muscle is neutral; that of muscle, after frequent contractions, is acid (Du Bois-Reymond); the interchange of oxygen and carbonic acid is doubled in active muscle. It has recently been stated that the temperature of a muscle is *lowered* at the beginning of a contraction, but that, after a few seconds, a rise of its temperature takes place, which, in a tetanised muscle, continues after contraction has passed off. Such a lowering of temperature, if established, might indicate an absorption of heat, or an increase of the latent heat of the muscular substance during its commencing action; whilst the subsequent elevation of temperature might be due partly to increased chemical changes taking place after contraction had ceased, and partly to the greater activity of the capillary circulation. The amount of heat evolved is said to be proportionate to the work performed (Meyerstein and Thiry).

The living muscular tissue has also important *electrical* relations. Thus, it is a good conductor of electricity, and it is also extremely sensitive to that agent, being very easily excited to contraction by it. Moreover, this tissue possesses within itself natural currents of electricity, which constitute what is called the *muscular current;* and, lastly, this normal current is more or less disturbed during the period of contraction of the muscle. Such currents are not peculiar to muscle, but are most marked in this tissue. Indeed, in all live muscles, when quiescent, in small portions of them, even in the minutest shreds which can be operated upon, electrical currents are constantly passing in certain definite directions. Their presence, their direction, and the disturbances to which they are liable, are detected, and determined, by means of extremely delicate galvanometers, constructed as just described.

For this purpose, it is not sufficient merely to place the pieces of muscle, or other tissue, between the ends of the very fine galvanometer wire, but special contrivances are needed to conduct the current from the soft tissue to the wire. In two glass vessels, Diagram A, containing a solution of common salt, are suspended, by means of metal holders, *m*, supported on glass insulating rods, *g*, two pieces of platinum, *p*, which are connected respectively with the two ends of the galvanometer wire, *d*, *d*. Little cushions of blotting-paper, *b*, supported on small shelves in these vessels, but rising above their edge, also dip into the

solution of salt; by absorption of some of the solution, they form two moist surfaces of contact, placed at a short distance from each other, upon which the piece of animal tissue experimented on, can be laid in any desired position, by means of a thin holder of glass. If the two moist

Diagram A.

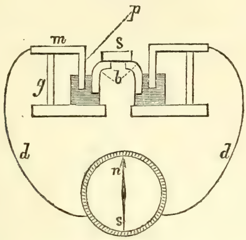


Diagram A (Vierordt). Apparatus for detecting the existence, direction, and strength of the normal electrical currents in animal tissues. *p*, one of the platinum plates, dipping into the solution of salt, contained in one of the glass cells; *m*, metallic connecting rod, supported on the non-conducting glass rod, *g*, and connected with the wire, *d*, of the galvanometer. The same parts are seen on the other side. *b*, indicates two small cushions of blotting-paper which dip into the solution of salt; *s*, is another cushion moistened with the same solution, which, when placed on the cushions *b*, completes the galvanometer circuit; but no current passes, as there is no chemical action set up. If the cushion, *s*, be removed, and a piece of living muscle or nerve be put in its place, instantly a current is formed, and the needle of the galvanometer, *n*, *s*, moves to the right or to the left, and shows the direction and force of the current.

cushions be first connected by means of a third cushion, *s*, moistened with the same fluid, the circuit is closed, but no currents are produced, the galvanometer needle, *n*, *s*, remaining quiescent, and the whole apparatus being in a state of chemical and electrical equilibrium; but when they are connected by a piece of living animal tissue, Diagram B, then a portion of any currents, which may exist in the tissue, is instantaneously conducted through the lateral moist cushions, the saline solution, the platinum plates, and the wire of the galvanometer. The needle immediately deviates to the left, 1, 2, or to the right, according to the direction of the current; and the relative amount of deviation in either direction, indicates the strength of the passing current, and the changes producible in it. In such experiments, only a portion of the intrinsic currents of a tissue is diverted through the galvanometer, so that the total strength of such currents cannot be thus ascertained; but their relative electrical activity in particular tissues, under various conditions, may be determined.

The muscles of the Mammalia, including man, give very strong currents; but those of the frog are usually employed in experiments, as the currents in them are more persistent. An oblong piece of muscle is so prepared, that its longitudinal surfaces correspond with the sides of the

muscular fibres, and its transverse sections with their ends. It is then placed, in various positions, Diagram B, 1, 2, 3, on the cushions of the apparatus just described, and the results on the galvanometer needle, *g*, are watched. When so placed, it is also made to contract, by any appropriate stimulus, and the effect on the galvanometer needle is recorded.

In a piece of living quiescent muscle, Diagram B, 1, 2, currents are found constantly passing from the longitudinal surface

Diagram B.

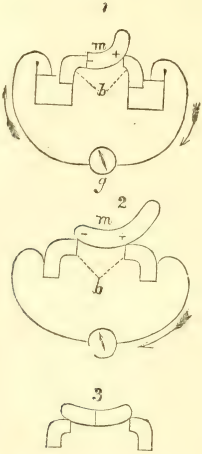


Diagram B (Vierordt). Views of pieces of muscle, *m*, placed on the cushions, *b*, of the preceding apparatus, in three different positions. In 1, the piece of muscle has its cut end in contact with one cushion, and its surface with the other; in 2, the piece of muscle has points at different distances from its centre or equator, touching the two cushions; in 3, the piece of muscle has points at equal distances from its equator in contact with the cushions, when no current passes.

or section, through the galvanometer, *g*, to either transverse section, i. e. from the sides to the two ends of its component fibres; so that the longitudinal surface or section of a muscle, or the sides of its fibres, are positive, +, and the transverse sections, or cut ends of the fibres, are negative, —. *Within the substance of the muscle*, however, the current passes from the cut ends to the lateral surfaces or sides.

A series of larger diagrams, Diagram C, will better serve to illustrate the course and character of these currents. The strongest currents are found to pass from the middle of the

piece of muscle, which might be called its equator, 1, *e*, to the centre or axis, *d*, of both of its two cut extremities or poles. From points of the longitudinal surface more or less distant

Diagram C.

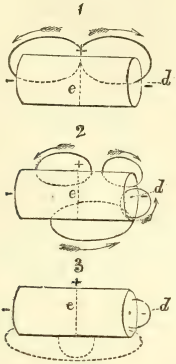


Diagram C (Author) shows the direction of the normal muscular current, both within and without the piece of muscle. 1, 2, 3, three cylindrical pieces of muscular tissue; *d*, the axis or pole, and, *e*, the equator of each piece. The black curved lines, with the arrows, in 1 and 2, show the direction of the muscular current outside the muscle, that is, as it would pass through the galvanometer circuit. The dotted curved lines show the path of the currents within the pieces of muscle. In 3, the dotted curved lines show lines of equilibrium, no current passing. In each piece, the signs + and −, show the electrical states of the equator and poles, or of the surface and ends.

from the equator, to points of the ends more or less distant from the axis, the direction of the currents is still the same, but they are proportionally weaker, 2. When two points on the longitudinal surface, equidistant from the equator, are touched, 3, no current is evident, an equilibrium being established; but when two points, unequally distant from the equator, are touched, 2, a feeble current is manifested from the nearer to the more distant point. In the same way, two points, at either cut end, equidistant from the axis, 3, give no apparent current; but if unequally distant from it, 2, they do.

To explain these remarkable electrical currents of the living muscular substance, it has been suggested by Du Bois-Reymond, that it possesses a peculiar electrical condition, which is supposed to be dependent on a special electrical polarity of the

component molecules or the disdiaclasts of the sarcous elements. Each molecule, in a given longitudinal row, Diagram D, is imagined to have its equatorial or central part positive, +, and its two ends, or poles, opposed to the neighbouring molecules, negative, −. In this case, a current would pass, *outside* the molecules, from the equator to the poles, but, *within* the mole-

Diagram D.

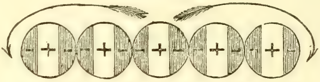


Diagram D (Du Bois-Reymond) shows the theoretical electrical condition of the molecules of muscular tissue. Each molecule in a series, is supposed to be peripolar, the adjacent ends or poles being negative or minus −; and the central or equatorial part, positive or plus +. The plus portion is shown white, and is marked + ; the minus parts are left black, and are marked −. The arrows show the necessary directions of the normal currents outside such an arrangement.

cule, from the poles to the equator. Each molecule, in such case, would represent, in miniature, the electrical condition of the entire piece of muscle. This supposed condition of the molecules, is named a *peripolar* electrical state. It exists in an artificial molecule made with a zinc equator and copper ends or poles, when immersed in dilute acid.

The muscular current in amputated limbs, also passes from the side of the limb to the cut extremity. It is manifested, as already mentioned, in even the smallest fragments of muscle, and also in the fibres of the heart, and in the non-striated muscular tissues. It remains for a time, though weaker, even when the contractility has already disappeared. In an entire muscle, the ends of which are not cut, it is stated by Du Bois-Reymond, that the currents have still the same direction, passing outside the muscle, through the galvanometer, from the sides or *natural* longitudinal surface, to the ends or tendons, or natural transverse surfaces of the muscle. In entire limbs, the current, supposed to be the *resultant* of the combined currents of the several muscles, runs, in the case of the frog, from the tips of the toes to the trunk, and, in the case of the entire body, from the coccyx to the head ; this is the so-called *total current* observed by Nobili. It is remarkable that the direction of the total current in the Mammalia, has the reverse direction, i. e. from the head downwards.

It is further stated by Budge that, in the sartorius muscle

of the frog, he found two currents; one, the so-called *natural* current, passing *in* the muscle, from its lower to its upper end, and the other, corresponding in all respects with that described by Du Bois-Reymond, which he names the *artificial* current, and which he says is present in muscles only after a transverse section has been made through them. The natural current, being always in one direction, whilst the artificial currents pass within the muscle, from the cut ends to the equator, it follows that the former strengthens the latter in the lower half, but opposes and weakens them in the upper half of the muscle. Budge enters into other details, which cannot here be described. The subject is yet open to much further enquiry.

Portions of nerve, as we shall hereafter see, exhibit precisely similar currents to those found in muscle, and these follow the same directions, though they are weaker and more difficult of detection. So likewise pieces of brain and spinal cord, give similar currents. Other parts, such as the lungs, liver, and kidneys, offer either very slight or no currents. In the frog's skin a current is developed, which is opposite to that of the muscle; for the section of the skin is positive, whilst the surface is negative.

The exact cause of the electric currents, present in living muscular and other tissues, is not understood. They are doubtless, in some way, connected with the constant molecular chemical changes of combustion or oxidation, which occur in the nutrition of the living tissues,—with those incessant changes, indeed, which are characteristic of life, and without which there is no life. But it is unknown whether such chemical changes are the consequences of the electric currents, i. e. are electrolytic; or whether, and this seems more probable, the currents themselves are the necessary accompaniments of the chemical changes. The nutritive molecular changes are doubtless more active in muscle than in nerve, and probably more so in nerves than in the skin; the strength of the electric currents obeys the same order. It is possible also that the nutritive changes are more active on the surface or sides of the fibres than at their centres or cut ends when they are divided; i.e. that they are more active on the surface of the fibres which is found to be positive, than on the parts which are negative.

The electrical current proper to, and constant in, healthy quiescent muscle, or the normal muscular current, is evidently disturbed by the contraction of the muscle. It was said by Matteuci to be reduced to zero, or even to be reversed in

direction; but by Du Bois-Reymond it is considered merely to be diminished, the needle being first deflected, in an opposite direction, when the piece of muscle experimented on is made to contract, but ultimately being merely less deflected than when the muscle is at rest. This diminution of the muscular current takes place all the same, whether the muscle be excited to contract by means of a direct stimulus, or by means of a stimulus applied indirectly through the motor nerve; nor does the nature of the stimulus, whether it be mechanical, chemical, or electrical, influence the result. The electrical current used to excite the motor nerve, may even be derived from the contraction of other muscles, as will hereafter be explained in describing the so-called rheoscopic frog's limb.

Cause of Muscular Contractility.

Various theories have been advanced as to the nature and cause of muscular contraction, but all may be dismissed as being unsatisfactory, and at present our real knowledge may be said to be limited to the phenomenon itself, and to certain of its conditions and accompaniments. Two very opposite general views have been, and are still, entertained by physiologists on this subject. According to *one view*, the muscular tissue owes its contractility to the nerves distributed to it, a certain force generated in the nerves being transferred, as it were, to the muscles, and so imparting to them their special irritability or contractile property. We have seen, indeed, that the muscular contractility may be excited through a nerve. In the living body, this is the ordinary mode of stimulation; and when the motor nerve of a muscle is divided, neither the will nor the so-called reflex nervous stimulus, both of which require that the nerves should be in connection with nerve centres, can any longer excite contractions in it. By irritating the portion of nerve connected with the muscle, movements can be excited, however, for a short time; but after a period, varying from four to eight days, this can no longer be accomplished, although the muscle may still be excited to contract by the direct stimulation of its fibres—a condition which may continue, though in a much less degree, for more than two months, but which at last is completely lost. This fact has been held to show that the contractility of muscle is not inherent, but is dependent upon, or derived from, the nerves still contained in it; for the separated muscle,

though continuously nourished, does not retain its contractility for a lengthened period. But a muscle, so separated from the nervous centres, is not permanently well nourished; it becomes atrophied or wasted, its fibres lose their transverse striæ, and undergo a fatty degeneration, so that both its structure and properties are destroyed. Moreover, its power of being *directly* stimulated, lasts longer than that of being indirectly excited through the divided nerve, and the frequent continuous application of galvanism to such detached muscles, will prevent their atrophy, and at the same time preserve their contractility.

These, and many other, considerations serve, therefore, rather to support the *second* and opposite *view*, celebrated from having been that adopted by Haller, and now very generally entertained, viz. that the muscular irritability is a special property of the muscular tissue itself, and inherent in it, a *vis musculosa*, or *vis insita*. The following numerous facts and considerations are usually quoted, as supporting this important doctrine in physiology. Nerves possess no contractility, but muscular tissue always does. Very small and isolated portions of single muscular fibres are seen to contract under the microscope. A contractile tissue is found in minute unicellular animal organisms, in which no nerve tissue has been shown to exist. Contractile tissues are met with even in certain plants, though these are believed to be absolutely destitute of a nervous system. Muscular contractions, it is alleged, will occur in the muscles of the embryos of animals, even whilst none can yet be excited by stimuli applied to the nerves. Subsequently to the division of its nerves, a muscle, provided that its nutrition is maintained, retains or recovers its power of contracting on the direct application of a stimulus, long after it ceases to act on the stimulation of the divided nerve. Chloroform and ether suspend the power of the nervous system over the muscles, so that stimuli applied to the nerves no longer excite muscular contraction, although the contractility of the muscle itself, as shown by direct stimulation of its fibres, yet remains, and although the effects on the sensory nerves lead us to infer that these reagents act quite up to the extremities of the motor nerves also. There exists, moreover, a special poison, the woorari or curare, which is said to have the power of destroying the vital properties of conductility of the nerves down to their finest extremities, and yet permits the muscles to retain their contractility on the

application of a direct stimulus. Lastly, in the case of a muscle like the sartorius muscle of the frog, which is provided with a nerve distributed to its central part only, the muscle can be made to contract at its extremities, after the destruction of the nerve itself (Kühne).

The preceding facts certainly tend to show that the muscular irritability is inherent in the muscle, and independent of the nerve. But a further question arises, viz. whether, granting that the muscular irritability is a property inherent in muscle, is it ever excited, or is it capable of being excited directly, or can it only be so, through irritation applied indirectly to it through the nerves? The minute distribution of the finest non-medullated extremities of the nerves among the muscular fibres, and their intimate connection with them, render it impossible to separate the effect of a stimulus upon the one and the other, so as to be able to say that a stimulus has acted on the muscle only, and not also on the fine branches of nerves mixed up with, or distributed upon, its fibres. The two last-mentioned experiments, viz. that on the effects of the woorari poison, and that on the sartorius muscle of the frog, are maintained by some to have solved this question, and to have shown that the inherent power in muscle is capable of being directly excited, i. e. *idio-motorially*, without the intervention of even the minutest extremities of the nerve fibres, as well as *neuro-motorially*, or through the agency of the motor nerves.

As to the ultimate cause of muscular contraction, it is quite evident that the slight condensation, if any, which takes place in the tissue during contraction, is wholly insufficient to account for the latter phenomenon. It is certain only that the tendency of the sarcous elements or disdiaclasts to alter their shape by shortening or widening themselves, and so to approach each other in a definite direction, is the essential fact in this remarkable phenomenon. Why they approach each other, is not yet explained. It has always been assumed that the state of contraction is the active, and the state of relaxation the passive, condition of the muscular fibre, and this is probably still the prevailing belief. But Dr. Radcliffe has advanced the opinion, from a study of the electrical relations of nerve and muscle, that the state of elongation should be regarded as the active condition of this tissue, and that of contraction as the passive condition, or state of rest. By an inversion of the ordinary terms of description all the phenomena can thus

be equally well explained, but the doctrine itself is not yet established. It seems natural to suppose, from our knowledge of the polar electrical condition of living muscles, and of the disturbance of its electrical state during contraction, that the dark sarcous elements or disdiaclasts, and the light intervening elements, may be in opposite polar electrical states; and that accordingly molecular attractions and repulsions may, under excitation, occur, as the immediate causes of motion between them; but this is quite conjectural. It has been offered as a mere suggestion, to be hereafter again alluded to, that osmotic changes in the contents of the tubular sarcolemma of the muscular fibre, may possibly occur as essential conditions of its alternate contractions and relaxations (Graham).

The Rigidity of Death, or Rigor Mortis.

Within a certain period after death, the muscles of the body, the muscular substance of the heart, and also the parts composed of the non-striated muscular fibres, undergo, after losing their irritability, a general stiffening, which is called the *rigor mortis*, or *cadaveric rigidity*, or the *rigidity* of *death*. This rigidity in the muscles is so perfect, that the joints become fixed, usually in the position in which the body lies at the moment of death; but, in certain cases, the occurrence of the rigor mortis is accompanied by displacements of the limbs, even to the raising up of the corpse into a sitting posture. Usually the more powerful muscles give, in dying, and in assuming their rigid condition afterwards, certain definite positions to particular parts of the body; thus, the upper eyelid is drawn slightly upwards, the lower jaw is closed against the upper one (whereas at the moment of death it falls by relaxation of its muscles), the fore-arm is slightly flexed, the fingers are bent, and the thumb turned inwards on the palm; whilst the leg and foot are everted and extended, the flexors of the upper limb and the extensors of the lower limb being stronger than their antagonists. These movements must be distinguished from those which have been observed, soon after death, in cases of cholera and yellow fever, and which are attributed to an unusual persistence of the proper muscular contractility.

The rigor mortis may begin within ten minutes of death, but it usually comes on between seven and eighteen hours, sometimes as late as thirty-six hours. Its usual duration is

rom twenty-four to thirty-six hours, but it may pass off much more quickly, or last for several, as many as six, days. It disappears at the commencement of putrefaction. The sooner it comes on the shorter its duration, and when it comes on late it continues longer. It appears latest, is most intense, and lasts longest, in persons dying rapidly in a state of health. In sickly, weak, and emaciated bodies, in new-born infants, and in animals exhausted by over-fatigue, it comes on quickly, is weak in its effect, and disappears most rapidly. It is independent of any influence from the nervous centres, for these may be destroyed without preventing its occurrence; and it occurs even in paralytic limbs, when the muscles are not too much impaired in their nutrition. A form of muscular rigidity can be induced in a living animal, by stopping the circulation through a limb; and the true rigor mortis itself may be completely removed by injecting defibrinated arterial blood into the arteries of a dead limb. If this be done within a short time after death, the irritability of the muscles is also restored: this effect has been kept up for forty-one hours, the opposite limb in the meantime beginning to putrefy. It would seem that the rigor mortis occurs more slowly, is most marked, and lasts the longest, in direct proportion to the previous amount of nutritive activity, and irritability, in the muscle. It was stated by Hunter that it did not occur in certain cases of death by lightning; but it has been observed in the body of a dog killed by electrical shock: it has also been said to be absent after death from severe injuries, or violent emotions; but in such cases it may have come on very quickly, and as rapidly disappeared. It often begins when the body is still warm. It occurs in drowned persons, and also in the corpse when immersed in water after death. It comes on sooner in cold weather, and in parts exposed to the air. In the human body, it first commences about the muscles of the lower jaw and neck, then proceeds to the upper limbs, next to the trunk, and lastly to the lower limbs; it passes off in the same order. The rigidity is completely destroyed by forcible extension; but if the extension be used before it is complete, the muscle may again become rigid.

By some, the rigor mortis is regarded as the result of a vital contraction, perhaps the last evidence of tonicity; but it commences when the contractility is already enfeebled; and even paralysed muscles become rigid. Moreover, the state of rigidity itself differs from that of the vital contraction of a

muscle, by its uniform and persistent character, and by the diminished cohesion or strength, the smaller extensibility, and the less perfect elasticity or resilient property of the rigid muscular substance, and particularly by the total cessation of all electrical currents in it. By others, it has been attributed to a molecular change in the sarcous elements of the fibrillæ, dependent on the stagnation of the blood-current; to a sort of coagulation or setting of the muscle-fibrin of the sarcous substance of the fibrillæ, compared to the coagulation of the blood (see p. 82); to the coagulation of a fibrinous material between the fibrillæ of each fibre (Brücke); or, lastly, to chemical changes giving rise to the production of an acid or alkaline fluid, which stimulates the still contractile muscle. According to this latter view, the rigor mortis is due to a last act of contraction, or idio-muscular contraction (Schiff). But its cause is not yet thoroughly understood. When fully established, it is an absolute sign of death.

In the case of the heart, the rigor mortis produces an excessive contraction of that organ. The occurrence of this phenomenon in involuntary muscle, is shown by the rising of water in a glass tube fitted into one end of a piece of the intestine of a recently killed animal, the other end being of course tied, and the cavity quite filled with water. It is also shown by the temporary contraction of dead arteries, which, after a time, again relax.

CILIARY MOTION.

The presence of *cilia* on certain so-called ciliated mucous and serous membranes in man, has been mentioned in the account of the ciliated epithelial tissues (p. 73); and it has been noticed that ciliated epithelium exists on similar membranes of both the warm and cold-blooded Vertebrata, and in various parts of the bodies of many Mollusca, Molluscoida, Annuloida, Cœlenterata, and Protozoa.

Cilia are found in man and other air-breathing Vertebrata, chiefly in the respiratory passages. They occur in man, in what may be called the middle region of the nasal cavities, in the frontal and other sinuses, in the upper part of the pharynx, in the larynx from below the vocal cords, and in the trachea, bronchi, and bronchiæ, down to the ramifications of the smallest bronchial tubes, but not in the air-cells of the lungs. They are present also in the Eustachian tube and

tympanum of the ear, and in the nasal duct and lachrymal sac. They are likewise found on the sides of the ventricles of the brain, and within the central canal of the spinal cord. In the warm-blooded Mammalia, they exist in the same situations as in man. In Birds, they are present likewise in the air-sacs distributed through the trunk of the body. Amongst the cold-blooded Vertebrata, cilia exist, not only in the ordinary situations, but, in Reptiles, in the pericardium, peritoneum and œsophagus, and also in the uriniferous tubuli, and sometimes in the Malpighian capsules, of the kidneys. In the frogs they are found also on the roof of the mouth ; and in the ichthyoid Amphibia, on the gills. In Fishes, the gills are destitute of cilia; but these exist in the cavity of the nose, and in the respiratory chambers, of the amphioxus. In the Mollusca and Molluscoida, cilia are found in the alimentary canal and bile ducts, and on the gills of both the univalve and bivalve kinds ; also on the respiratory apparatus, when this consists of simple tentacula (hydrozoa), or is reduced to a respiratory sac or atrium (tunicata). In the Annelida, cilia are commonly found on some part or other of the body ; and in the Annuloida, always in the so-called water-vessels and other parts of the scolecida, and in the ambulacral tubes of the echinodermata; also in most aquatic Annelida and Annuloida, on certain parts of the head, probably the seats of an olfactory sense. In the Cœlenterata, they are found very largely developed on the bodies of the ciliograde actinozoa (Beroe, &c.), on the ovarian fringes, and in the interior of certain tubes which ramify through the bodies of the medusoid forms. Lastly, in the Protozoa, they are invariably present upon the surface of all infusoria, and in the interior of certain parts of the ramified tubes of the spongida. They exist, moreover, on the embryos of the amphibia, on the ova or embryos of a large number of the non-vertebrated aquatic animals, and on the gemmules of others. Cilia have not been found in insects, crustacea, myriopoda, or arachnida.

The cilia are microscopic, soft, transparent, colourless, homogeneous, flexible organs, which, from being, in certain places, arranged in even rows, have been compared to the eyelashes, and hence have received their name. They are either thread-like, tapering, blunt, or flattened; they are usually attached to epithelial or epidermoid cells—each cell, in the most characteristic forms, bearing from six to twelve cilia. They vary in length from $\frac{1}{2500}$th to $\frac{1}{4000}$th of an inch in man, and

rom $\frac{1}{12000}$th to $\frac{1}{1000}$th of an inch in different animals, being argest in the non-vertebrate marine animals, and reaching heir greatest size in certain Cœlenterata. On the mucous nembranes of the warm-blooded Vertebrata they are less egular in their distribution over the surface; but on the gills of the Mollusca, on the tentacles of the hydrozoa, on the lateral ands or paddles of the Beroe, and on the bodies of certain nfusoria, they are arranged in remarkably even lines, and, in ach particular case, have a very uniform length.

The ciliary movements are, of course, only observable by id of a high magnifying power. The motion of individual ilia is difficult of detection, owing to its rapidity. It is ometimes *infundibuliform ;* that is to say, the point describes circle in space, which forms the base of a cone or funnel, he apex of which is at the attachment of the moving cilium. Iore commonly the movement is *unciform* or hooked, each ilium bending downwards and then straightening itself again, as to perform a *lashing* movement. In the case of a ciliated urface, this motion appears to affect the cilia in regular sucession, so that the result is an *undulatory* movement, like at of running water, moving rapidly along in constantly efinite wavy lines. Nothing can exceed in beauty, as a icroscopic object, these waving movements of the fringed and atherlike rows of the ciliated gills or branchiæ of one of the Iollusca (mussel, oyster). The average velocity of the ciliary urrent in the frog's mouth is about $\frac{1}{200}$th of an inch per cond, the average rate of the blood in the capillaries of its eb being about $\frac{1}{50}$th of an inch per second.

The motion of the cilia has the effect, when the animal is ced, of producing currents over the ciliated surface in the rrounding fluid medium, in certain definite directions, by hich not only the fluid, but any small particles or microopic living objects which it may contain, are hurried past over the surface. Indeed, the ciliary movement is best served and detected, by mixing charcoal or pigment in the uid in which these organs are examined. In the case of small uatic animals, and of ciliated ova, embryos, or gemmæ of the me, the effect is to cause a movement in those minute beings emselves, the cilia constituting true locomotive organs. This curs also in the Beroe, the lateral ciliated bands of which are mposed of flat quadrangular plates, built up of large cilia, ced side by side. Most commonly, the direction of the ogressive movement is constant, and remains unchanged

even on any detached pieces of membrane; but sometimes th motion, as in the case of certain infusoria, is variable in direc tion, and almost suggests obedience to volition. In the Beroe this is even more obvious. On the gills of Mollusca, the direc tion of the motion is likewise sometimes suddenly reversed.

The ciliary motion continues for one, or sometimes fo several days after death, in the amphibia and other cold blooded Vertebrata, as in the turtle, though for a shorter tim in the warm-blooded Vertebrata, often ceasing in birds afte the lapse of fifteen to thirty minutes. It endures longer however, in Mammalia, the time varying from two to forty eight hours; it lasts longer in warm than in cold weather The ciliary movement continues for a time on portions of th mucous membrane, detached from the body; and is said t have been observed in the fresh-water mussel even in a state c putrefaction. It is quickened by touching the cilia briskl with a foreign body; also by contact with the serum of th blood. Blood preserves the power of movement, for cili immersed in it, exhibit motion at the end of three days, whils water destroys it in three hours. The blood of the Vertebrat arrests the action of the cilia of the Invertebrata. Light doe not affect the motion, nor electricity, unless it be strong enoug to destroy, or chemically decompose, the tissue. This curiou movement is increased in rapidity, and may even be revived by the action of heat: it is diminished by cold; thus i warm-blooded animals, it ceases at a temperature of 43 whilst in the frog, it continues even at the freezing point c water. It is retarded by water, and destroyed by variou chemical agents, by bile, or even by fresh water, in the case c marine Mollusca; but weak alkaline solutions revive it. Th motion is not influenced by narcotics generally, nor yet, it i said, by some poisons which annihilate muscular contractility but prussic acid may affect it, and it is temporarily suspende like the muscular action of the frog's heart, by the vapour c chloroform. No nerves have been traced to the cilia, nor d they appear to be governed, or influenced, through the nerve or nervous centres; their motion continues in the frog, fo days after destruction of the brain; they exist in animal apparently destitute of nerves; and, lastly, motion may con tinue in a single cilium detached, with its epithelial cel from the rest of the body. Furthermore, they have been see in action in the turtle after the muscles have ceased to exhibi any signs of contractility.

The true explanation of the phenomenon of ciliary motion has yet to be discovered. By some it has been supposed that the cause of the motion is *not intrinsic*, but that it is dependent solely upon certain chemical interchanges between their substance and the surrounding medium. The opposite view, that it is due to the action of an animal substance endowed with a form of vital contractility, seems more probable (Sharpey). No trace of muscular fibres, or fibrillæ, has been found at their base; their motion differs most remarkably from muscular motion, in not being affected by electricity of moderate intensity, or by certain narcotics, and also in lasting much longer after death. But, on the other hand, no particular structure seems to be essential to the possession of contractility, which is manifested equally in the striated and non-striated fibres, in the simple fibre cells, and, as well known, in other single sarcodous cells, and even in masses of protoplasm; it is also exhibited in the heart of the embryo chick, where this is composed solely of nucleated cells, having no fibres developed in it. On this point, too, it has been suggested that the cilia may consist of extremely delicate protrusions of the wall or periplast of the cell on which they rest, like the fingers of a glove, each containing a soft contractile sarcodous material (Kölliker); or, that they may be gymnoplastic offshoots, that is, destitute of a distinct envelope. Again, the longer duration of the movement after death, is only a difference of degree; and this power endures longest in those animals in which muscular contractility lasts longest. Finally, the discrepant action of certain narcotics may be probably explained by future researches. Admitting, however, the probability of the ciliary motion being due to a vital contractility, its rapid, rhythmic, concerted, and maintained action yet remains to be explained.

The *use* of the cilia in the respiratory organs of the higher air-breathing animals, may be said chiefly to be to keep the membranes moist, by distributing over them the secretion from their surfaces and follicles; and secondarily, by the definite direction of their motion, which has been noticed invariably to be upwards towards the larynx, to assist in raising and expelling the superabundant secretion upwards from the air-passages. Their use in the ventricles of the brain, and central cavity of the cord, is not known. On the gills of the young Amphibia (tadpoles), and on the respiratory organs, whether laminated, ramified, or sacculated, of the aquatic Mollusca and Molluscoida, they appear to assist in the respiratory process,

by keeping up rapid and continuous currents over the respiratory surface, by which fresh portions of fluid are continually brought into contact with it. In certain cases (Ascidioida, Polyzoa), by creating currents, they also serve to conduct alimentary substances into the opening leading into the stomach, or the mouth, of the animal. As already mentioned, they cause a rotatory movement of the embryos of certain vertebrate and non-vertebrate aquatic animals. Finally, they constitute the proper locomotive organs of the entire animal, in the Infusoria: in some of these (Paramecium) the whole surface is ciliated; sometimes, as in Vorticella, there are a few ciliated fringes only around the mouth; and sometimes, as in the young Vorticellæ, and in other species, there is but a single long tail-like cilium, by the undulatory motion of which, the microscopic being is propelled through the water, in the opposite direction.

MOVEMENTS OF ANIMAL SARCODE AND PROTOPLASM.

Movements, undoubtedly due to a vital contractility, take place, as we have seen, in cells not possessed of the complex structure of muscular fibre; such are the movements in the contractile cells of the embryo heart of the Vertebrata, as in the chick or tadpole. In many of the Annelida, and in other animals still lower in the scale, distinct muscular fibres are replaced by an almost homogeneous tissue; the cells of the Hydra, formerly believed to be themselves contractile, are not now so regarded; but are considered as being rather of an elastic nature, having contractile tissue lying between them. Still simpler examples of sarcodous contractile movements, occur in the gymnoplastic white corpuscles of the blood, and in the so-called uni-cellular organisms of a gymnoplastic type, such as the compound amœbiform particles of the Spongida, and the various Rhizopoda, such as the Rotalia, the Actinophrys, and the simple Amœba itself, and lastly, in the still lower Gregarinida. In all these cases, there is noticed a retraction of a soft tissue in certain directions, accompanied by its extension in other directions; this is the essential character of muscular contraction, even in the highest organised fibre. In the more perfect contractile cells, there probably occurs an approximation of true sarcous elements or particles, filling the entire cell; but in the simpler animals above mentioned, as in the Amœba, for example, the movement is confined to the

outer firmer layer of amorphous sarcodous substances, the inner portions being semifluid or fluid. All the preceding movements, like muscular contraction, can be excited by electrical, mechanical, or chemical stimuli.

Movements yet more obscure, have been seen in mere masses of protoplasm not organised into the distinct cell form, either cystoplastic or gymnoplastic, but merely irregularly aggregated around a nucleus. Such are the budding movements which have been observed in the lymph corpuscles, and also in the little stellate masses of nucleated protoplasm, known as the connective tissue corpuscles, which in the frog, especially in the cornea of the eye, have been seen to extend themselves in various directions. They are excitable by electrical and mechanical stimuli, and, in the case of the corneal corpuscles, even through the nerves. The curious movements which take place in the pigmentary contents of the coloured cells of the frog's skin, also seem only to be explicable on the supposition of the occurrence of like protoplasmic movements.

However simple these sarcodous and protoplasmic motions may be, they are all similar, or at least allied, to those of the sarcous elements of muscular tissue, and the dependence of all on a common vital property seems undoubted, though it may be sometimes actively, and at others obscurely, manifested. Retraction and extension, in different directions, always occur; but these movements are sometimes rapid, and sometimes slow; sometimes they are neuro-motor, and sometimes idio-motor. If the ciliary motion be included in the same category, its extreme rapidity, and its rhythmic and combined character, apparently irrespective of nervous influence, are quite peculiar.

Vegetable Motion.—In the vegetable kingdom, two kinds of movements have been observed. Thus, for example, the motions of the leaves of the sensitive plant, of the fly-catching plant, of the stamens of the berberry and other flowers, and of the bifid stigma of the mimosa, may be due to physical changes of an osmotic character, causing a filling or emptying of certain cells; or, as is alleged, in the case of the stamens of the centaurea, the movements may be owing to the action of a true contractile tissue, vegetable sarcode, or protoplasmic substance, contained in a cell (Cohn). The rapid motions of the fertilising spiral filaments, known as spermatozoids, in the ferns, lycopodiums, and mosses, seem to be analogous, though this is not certain, to the ciliary motions of the singly-ciliated infusoria. The motions of the algaceous volvocinæ, desmidiæ, and others, are almost certainly protoplasmic. Lastly, the remarkable and well-known movements of the contents of certain cells in the vallisneria, chara, and other plants, are of a protoplasmic

character: in these cases, globules of chlorophyll, and other minute particles, are seen to move along, in fixed directions, round the interior of the cells, passing, when these are oblong, up one side and down the other, in regular and continued order—the movement really occurring in the fluid contents of the cells, and the solid particles being thus carried along. It has been supposed that the cells were provided with cilia on their internal surface; but of this there is no proof. It would rather seem that the internal surface of the periplast or cell-wall, is lined with a layer of contractile protoplasm, in which progressive undulatory movements take place; but how these are caused or regulated, is unknown. It is interesting to find in these various vegetable movements, if not an identity with, at least a simulation of, the lowest forms of animal contractility and movements.

MOVEMENTS OF MAN AND ANIMALS.

The various kinds of motion which we have now considered, whether muscular, ciliary, sarcodous, or protoplasmic, are employed, as we shall hereafter see, both in man and animals, not only in the functions of animal life, as in motion and sensation, but also in those of vegetative life, as, for example, in the actions of the digestive apparatus, of the organs of circulation, and of those of nutrition, secretion, excretion, respiration, and reproduction. The movements of *animal life*, properly so called, which have now to be considered, have for their immediate purpose, either the performance of the various acts of *locomotion*, *prehension*, or *manipulation*, or they may aid in the *exercise* of the organs of *the senses*, or they may be called into play in *expression*, or in the production of *voice* and *speech*. In reference to these intrinsic movements, the animal body may be regarded as a machine, differing from ordinary machines, in being endowed with life, in possessing within itself a source of action or power, viz. vital contractility, and in being composed of certain mechanical parts destined to be moved on each other, except in the lowest forms of animals, in subjection to the internal control of the nervous system, so as to yield *intrinsically* regulated mechanical effects.

Thus, in locomotion, the body, entirely, or by its parts, acts on some external medium, whether solid, fluid, or aërial; and, in consequence of the resistance or reaction of that medium, is moved through space. In prehension, and its higher form, manipulation, certain parts of the body seize, act upon, and

utilise materials external to it, according to the innumerable dictates of want, desire, or reasonable will. In aiding the sensory organs, movements are impressed either upon the head, or upon the various sensory organs, or their parts, or appendages. In expression, all parts of the body may be set in motion, but in the higher animals, and in man particularly, the features. In the production of voice, peculiar and rhythmical vibrations of a special part of the frame of air-breathing animals, accompanied by synchronous vibrations in the air, are generated by movements set up in the respiratory apparatus. Finally, speech, which is peculiar to man, and results from the modification of vocal or whispered sounds, is due likewise to muscular actions which are accomplished by the throat, mouth, and lips.

LOCOMOTIVE ORGANS IN MAN.

The parts of the body concerned in locomotion, are usually divided into the passive and active organs of locomotion. The passive organs consist of the bones, joints, ligaments, both fibrous and elastic, and tendons; whilst the active organs are the muscles.

The Bones.

The names of the bones, and their position in the body, are elsewhere mentioned; the microscopic structure of the osseous tissue has also been explained.* The bones support

* A few additional details may be here given concerning the structure of bone. The laminæ or lamellæ, as they are called, are either concentrically disposed around the Haversian canals, or they are placed parallel with the general surface of the bone, or they are irregular, and fill up the general substance of the compact tissue. The fibrous structure of these lamellæ is now well established: when decalcified, by soaking in an acid, they are seen to consist of transparent decussating fibres arranged in a compact reticulated manner. The lamellæ are, moreover, frequently perforated by bundles of other fibres, which serve, as it were, to connect them together: these perforating fibres, when decalcified, generally resemble white connective tissue fibres, but some have been compared to elastic fibres. The lacunæ of bone, as shown after maceration in acid, contain each a nucleated cell, which presents an irregular outline like that of the lacuna itself, and is regarded as corresponding with the so-called connective tissue corpuscles (Virchow). Besides the cancelli of the cancellated or spongy tissue of bone, and the short and frequently communicating Haversian canals of the compact

and protect the soft parts of the body, as well as give effect and precision to the actions of the muscles: for these purposes, the bones are hard, somewhat elastic, and resistant. The hardness and strength of bone are sufficiently well known; its elasticity is well exemplified in thin long bones, like the ribs. The hollowness of the long bones, endows them with a greater comparative strength than if the same weight of bony tissue had been employed in the solid form; for it is a well-known fact in physics, that the same weight of material affords more resistance, both to downward and lateral pressure or force, when arranged in a tubular form, than it does when disposed in a solid cylindrical mass of equal length. Independently of its strength, due to the grosser mechanical form or distribution of its substance, the osseous tissue, owing to its microscopical structure, is endowed with a remarkable innate strength and elasticity; for the compact bone, it will be remembered, consists of innumerable interlacing fibres, disposed in the form of numerous concentric laminæ, surrounding the minute branching Haversian canals, and themselves cemented together into one firm mass. Moreover, the cancelli and larger hollows of the bones, serve to expand their surfaces, and so present broader points for contact with each other at the joints, and broader surfaces for the attachment of muscles. The compact bone is found in the shafts of the long bones, and in other parts where strength is needed; whilst the cancellated structure prevails at the ends of the long bones, and in the parts of the vertebræ that rest over one another. The cavities in bone also secure a greater relative amount of lightness in reference to bulk, for the cancelli and the larger medullary cavities, are filled with a vascular fatty tissue, much lighter than bone; and in certain cases—as, for example, in the

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tissue, other spaces are occasionally found in the latter, especially in growing bone; they are produced by a process of absorption, and when first formed are irregular in outline, frequently encroaching on neighbouring lamellæ; they are named Haversian spaces. The periosteum, which covers the bones everywhere, except at the articular surfaces and on the smooth grooves for tendons, consists of an outer layer composed of white fibrous tissue and bloodvessels, and of an inner layer of elastic fibres. Besides the yellowish marrow, which exists in the long bones, and is composed chiefly of adipose cells, there is in the short bones, and in those of the cranium, a reddish and more transparent medulla, which contains only a few fat cells, but numerous minute spheroidal nucleated cells, or proper *marrow cells*.

frontal, sphenoidal, and maxillary bones—there are spaces occupied by air.

The bones of Fishes, the bodies of which are supported in water, are perfectly solid, whether their skeleton be osseous or cartilaginous. In Reptiles, there are comparatively few medullary cavities or cancelli. These exist in all the Mammalia, but are less marked in the aquatic cetacea. In Birds, many of the bones, which in the Mammalia are occupied by fat, are filled only with warm air.

Other mechanical arrangements in the skeleton also deserve attention; for example, the broad expanded shape of the skull-bones and pelvic bones, for the purpose of protection; the length of some bones, as those of the limbs, where they are destined to act as long levers with unequal arms; the shortness of other bones, as those of the vertebral column and foot, where shock has to be lessened, without any sacrifice of strength, and with the preservation of flexibility and elasticity; the projecting points, or the so-called '*processes*' of many bones, which serve for the attachment of muscles, and, as we shall see, also increase their leverage; the formation of *grooves* for the play of tendons; and, lastly, the presence of holes called *foramina*, for the passage of nerves and vessels. Special adaptations of the forms of different bones to their several purposes, will be exemplified in describing the habitual posture, and the various movements, of man and the lower animals.

The Joints.

The *joints*, or *articulations*, permit the various movements of the animal frame; they likewise serve to deaden the internal concussion or shock produced by contact of the body with external objects, and, moreover, they contribute to the strength of the skeleton, especially to that of the back and lower limbs; for it has been shown mechanically, that a rod or pillar, of a given height and thickness, has less power of resistance to vertical pressure or crush, than a number of shorter rods or pillars built up one above the other to an equal height. Whilst the muscles are the active agents in the movements of the body, and whilst the bones give effect and precision to those movements, it is the form of the surfaces of the bones at the joints, which finally determines their exact character and extent.

The joints, in man and the higher animals, are first divided

systematically, according to the degree of movement permitted by them, into three different kinds, named the immovable, the mixed, and the movable joints.

The *immovable* joints (synarthroses, from σὺν, *sun*, together, ἄρθρον, *arthron*, joint) include the several kinds of *suture* (sutura, a seam), fig. 8. The *dentate* or *serrated* sutures occur in the junction of the bones of the upper part and sides of the cranium. In them, the indented or serrated edges of the adjacent bones fit into each other, having, however, a thin layer of fibrous membrane passing between them, which is derived from the periosteum and dura mater, and serves not only to unite and nourish them, but to deaden shocks. The suture is called *squamous*, where the adjacent margins of the bones are bevelled off, so that one overlaps the other, as at the junction of the temporal and parietal bones. Sometimes the direction of the bevelling is changed at different parts of the same suture; for, at the upper part of the skull, the frontal bone overlaps the parietals, whilst at the sides the parietals overlap the frontal—an arrangement evidently calculated to stiffen the tie between the two bones. Where the borders of the adjacent bones are elevated, the suture is said to be *limbous* (limbus, a selvage), as in the union of the parietal and occipital bones. In some sutures of the skull, as between the upper jaw bones, the palate bones, and others, the opposed margins are smooth or even, and form a *false* suture, named *harmonia* (ἄρειν, to fit). Sometimes a ridge in one bone is received into a groove in another (*schindylesis*, σχινδύλησις), as in the junction of the vomer with the ethmoid. The fitting of the teeth into their sockets, erroneously classed with the joints, is called *gomphosis* (γόμφος, gomphos, a nail).

The *mixed* articulations (*amphiarthroses*, ἀμφὶ, together, or both, αρθρον, a joint) are those in which the opposed surfaces of the bones are joined directly together by some intermediate soft substance, which is fibrous externally, and more or less fibro-cartilaginous towards its central part. The best examples of this joint are found, in those between the bodies of the movable vertebræ, from the second downwards, figs. 9, 10, 12, in the junction of the body of the last vertebra with the sacrum, and in the articulation between the two upper parts of the sternum. The symphysis pubis, or joint between the two hip bones at the front of the pelvis, and the joints between the ilia and the sacrum behind, also possess the same general

characters, but, in some respects, approach the more perfect or movable articulations. The mechanical result obtained in these articulations, is great strength, accompanied by slight movement; they serve, in all cases, to deaden shock, and to give elasticity, and, in the case of the movable vertebræ, they allow of limited motion, in all directions, between the numerous individual bones, the total result being considerable flexibility, and possibility of curvature, in the whole column.

The *movable* joints (*diarthroses*, διὰ, through, ἄρθρον, a joint), so called because the severance of the surfaces is complete, these not being joined, but being merely in contact with each other, are the most perfect articulations in the animal economy. In them, the ends of the bones are often expanded and variously shaped, according to the character of the joint, the end of one bone being usually convex and of the other concave, fig. 3. These ends, or *articular surfaces* of the bones, are moreover covered by a thin layer of closely adherent *cartilage*, which serves to deaden shock, and to facilitate, to the utmost degree, the movements of one bone upon the other. Surrounding the joint closely at all sides, and attached to the opposed bones, near the borders of their cartilaginous articular surfaces, is a membranous sac or closed tube, called the *synovial capsule*, which limits the joint, and secretes a viscid fluid named *synovia*, which serves to lubricate the articular surfaces, and so diminishes friction and prevents the perception of grating, or noise, to the individual. This ropy fluid escapes when a joint is opened, and is vulgarly called *joint-oil*, though it is not of an oily or greasy nature, but is an albuminous liquid, which has an alkaline reaction and a slightly saline taste; it resembles the white of egg; hence its name (from σὺν, *sun*, like, ὠὸν, an egg). Outside the synovial capsule, and more or less blended with it, are the proper connecting tissues between the bones, or the special *ties* of the joint, called the *ligaments* (from ligare, to tie). These ligaments are composed of white fibrous connective tissue. In certain parts, the fibrous bands of which they consist, are spread out, and merely strengthen slightly the loose synovial capsule; at other parts, they are collected into dense bands of various shapes, tying the bones very firmly together. Besides permitting motion between the bones, the ligaments are generally so inserted around each articulation, as to restrain the movements in certain directions, or at some determinate point. Sometimes the muscles, or else the tendons of muscles, exercise what might be called a

ligament-like protection around a joint; as, for example, the muscles around the shoulder, and the tendons around the ankle-joint. The articular surfaces of the movable joints, are also held together by the atmospheric pressure which acts on the whole body. This is best exemplified, experimentally, in the ball and socket-joints, and especially in the hip-joint, as will be presently mentioned.

The movable joints, or diarthroses, are classed in *three* divisions, according to the shape of their articular surfaces, and to the character of the movements performed at them. In the simplest form, the surfaces are more or less plane, and the movements gliding: these are the *planiform* joints, sometimes called *arthrodia.* They are met with chiefly, in the tarsal and metatarsal articulations of the foot, and in the carpal and metacarpal articulations of the hand; also in the articulations of the collar-bone with the scapula and with the sternum, in the articulations of the lower jaw bone, in the junction of the upper end of the fibula with the tibia, in the joints between the occiput and atlas, and between the articular processes of the several cervical and dorsal vertebræ, in the junctions of the tubercles of the ribs with the vertebræ, and in those of the costal cartilages with the sternum. The ligaments of such joints are usually short and strong, especially in the foot and hand, and, together with the neighbouring processes of bone, serve to check the movements of the bones. These joints allow of limited motion in many directions, deaden shock, and impart elasticity and slight flexibility, without impairing the strength of the part in which they are found.

The second kind of movable joints have *pulley-like* surfaces, and execute *hinge-like* movements; hence they are called *trochlear* (from trochlea, a pulley), or *ginglyform* (γίγγλυμος, a hinge). In these joints, the end of one bone is modelled so as to present a median groove with two lateral projections; whilst the end of the other bone has a median projection and two lateral concavities; or the surfaces are otherwise adapted by opposing curves, so as to admit of free motion in one plane only, though, of course, in two directions, viz. backwards and forwards. The best examples of this kind of articulation, amongst the larger joints, are to be found in the elbow, the ankle, the wrist, and the knee (fig. 3); the knee being the least perfect, because, when flexed, it permits of slight rotation. In the smaller joints, the articulations of the phalanges of the fingers and toes with one another, are

also examples of hinge-joints. In these joints the ligaments, on one aspect, which may be called the aspect of extension, from which the joint can be most strongly bent, are more or less thin and loose; whilst at the sides, and on the aspect of flexion, they are, as a rule, very strong: this twofold arrangement gives the necessary strength to a hinge-joint, without impeding, or preventing, its almost complete flexion. In the knee, especially, the lateral ligaments and the posterior ones, which project into the back of the joint, and have a *crucial* form (figs. 3, 8), serve to check the extension of the leg upon the thigh, when the one is in a line with the other; and, in the act of standing, when the weight of the body is thrown upon the fully extended knee, these ligaments save the expenditure of much muscular force. In the case of the fingers and toes, the flexor and extensor tendons act as additional ligaments to the joints.

The third kind of movable articulations have *ball and socket* surfaces, and power of movement in all directions; they are named *enarthrodia.* In these joints, the one bone presents a cuplike cavity, or *socket*, either shallow or deep, lined, of course, with cartilage; whilst the other bone presents a rounded extremity, forming, more or less, part of a spheroid, and also covered with its cartilage. When the receiving cavity is shallow, it is called a *glenoid*, when deep, a *cotyloid* cavity. Examples of the ball and socket joint are met with, in the hip, which is the most perfect of these joints in the body; in the shoulder; in the head of the astragalus, amongst the tarsal bones, where this moves in the cup-shaped cavity of the scaphoid bone; in the head of the os magnum, amongst the carpal bones, where it articulates with the scaphoid and semilunar bones; and, lastly, in the several joints at the *bases* of the fingers and toes, where these articulate with the rounded heads of the metacarpal and metatarsal bones. The synovial capsule of the ball and socket joints, is generally loose; but it is fortified by strong ligaments in certain positions, where the motion requires to be restrained. In the larger joints of the shoulder and hip, the cavity of the socket is deepened by a fibrous rim, or border, attached all round its margin. In the shoulder, the tendon of the biceps muscle passes through the joint, and, undoubtedly, exercises a ligamentous control over it, and affords it support; whilst, in the hip, an internal ligament, named *ligamentum teres*, passes from one bone to the other, that is, from the pelvis to the head

of the femur, within the joint, offering an exceptional structure in the anatomy of joints, and serving as an important check ligament, which is brought into use in the act of standing. The hip-joint is very secure, and yet the movements which it permits in the thigh, are very free; for the thigh may be moved so as to make with the trunk the following angles: forwards, 130°; backwards, 40° to 60°; outwards, 90°; and inwards, somewhat less. If the hip-joint be exposed, and the synovial capsule be opened, the head of the bone remains in the socket, or acetabulum. This is due, neither to the ligamentum teres, nor to the fibrous rim which deepens the socket, but to atmospheric pressure; for, on making a small aperture from the pelvic cavity through into the socket, air enters, and the head of the bone falls out (Weber). The same thing happens if the opened joint be suspended under the receiver of an air-pump, and the air be then exhausted.

There are certain forms of movable joint, which require special description. The articulation between the upper ends of the *radius* and *ulna*, sometimes named *diarthrosis rotatorius*, or *lateral ginglymus*, may be called a *ring*, or *collar*-joint; for the side of the head of the radius, convex in shape, is received into a little cuplike cavity on the side of the ulna, from which a strong ligamentous ring or collar, 4, fig. 54, passes completely round the head of the radius, tying it to the ulna, and permitting the former bone to rotate round its long axis, whilst resting upon the latter. The joint between the *atlas* and the *axis*, is also somewhat similar in principle, but differs in its details: thus the dentate process of the second vertebra, or axis, is received into the anterior part of the ring of the atlas, and is held in position by transverse and vertical bands of ligaments crossing behind it, named the *crucial* ligaments; but the second vertebra is also connected to the skull, for two check ligaments pass from the tip of the tooth-like process, obliquely up to the occiput, and prevent the head from rotating sideways beyond a certain point. The articulation between the *first vertebra* and the *occiput*, is effected in reality by two small gliding joints, the occipital condyles, which project downwards on each side of the foramen magnum, being received into two concave surfaces formed on the atlas. As there are here two separate joints, one on each side of the median plane, the movement is limited to a *rocking* motion, forwards and backwards. The *nodding* motion of the head is accomplished

between the cranium and first vertebra of the neck; whilst the *rotation* of the head from side to side, carries the atlas with it upon the axis; the upper part of the spine may participate in both these movements.

In certain other joints, plates of fibro-cartilaginous tissue are interposed between the articular surfaces of the bones. Thus, in each of the two articulations of the *lower jaw*, by means of its two condyles with the very shallow glenoid fossæ of the two temporal bones, there is such an *inter-articular cartilage*; this is either very thin, or perforated, in its centre, but thick at its margins; it is perfectly movable, though attached to the synovial membrane all round, and it follows the movements of the jaw, so as to guard it from dislocation. The double character of the articulation of the lower jaw with the temporal bones at the base of the cranium, also necessitates a hinge-like action of this upon the skull; at the same time, other slighter, lateral, and backward and forward, movements are permitted. Again, between the inner end of the *clavicle* and the *sternum*, there is also an inter-articular fibro-cartilage, which passes obliquely from the upper border of the collar-bone to the cartilage of the first rib, close to the lower border of the socket in the sternum. This direction is the one best fitted to resist thrusts or shocks coming from the shoulder, which must constantly take place in the action of the upper limb. Passing sideways from the *lower end of the radius* to the lower end of the *ulna*, is another fibro-cartilage, 8, fig. 54, which ties those bones together, whilst it permits the radius, which is marked on its inner side by a slight concavity, to roll or rotate on a corresponding convexity upon the ulna. Lastly, in the *knee-joint*, are two remarkable fibro-cartilages, having a more or less crescentic form, and hence called the *semilunar cartilages*. They rest on the upper end of the tibia, and present their convex thick borders towards the outer and inner sides of the joint respectively, where they are attached to the synovial membrane and ligaments, whilst their thin concave borders are turned towards each other, i.e. towards the centre of the joint; they serve to deepen the two shallow sockets on the head of the tibia, into which the condyles of the femur are received.

Elastic ligaments.—Between the arches of all the movable vertebræ, with the exception of the atlas and axis, also between the arch of the last lumbar vertebra and the corresponding part of the sacrum, very peculiar ligaments are found,

differing in nature from the white fibrous ligaments which, as their office requires, are essentially non-extensible. These peculiar ligaments, the *ligamenta subflava*, are composed of yellow elastic tissue, and are highly extensible and elastic; they not only serve to connect the bones, but exercise a special mechanical office, yielding, for example, to permit of the slight separation of the vertebral arches from each other in the forward bending of the spine, and assisting mechanically, by their elastic recoil, in the re-erection of the body, and in its due maintenance in an upright posture, thus counteracting the effect of the muscles which would flex the spine. The yellow elastic tissue, indeed, is used here, as elsewhere, in the economy, to sustain weight or any force, or to overcome constant resistance, without the expenditure of muscular power.

The *tendons*, *fasciæ*, and *sheaths* of the muscles.—The *tendons of the muscles*, as we shall immediately see, serve to convey the muscular force from, and to, definite parts of the skeleton, and should therefore be regarded amongst the passive organs of locomotion; they have merely mechanical functions, whether they be considered as adjuncts to the muscles, or as contributing to the support of the joints over which they pass. The *fasciæ*, too, are strengthened in certain parts, and are so arranged as to enclose, or bind down, subjacent muscles, generally or individually, in special *sheaths*, and so prevent them diverging from their required lines of action; and it is certain that they aid in muscular efforts, by holding and supporting the muscles. They are therefore, likewise, passive organs of locomotion. Even the loose cellular tissue, which immediately invests the muscles, and facilitates their constant changes of form and position, may be similarly regarded.

The Muscles.

The microscopic structure and the vital properties of the muscular tissue, both in man and animals, have already been fully described (pp. 49, 156); and also the general mode of construction of the muscles (pp. 13, 51). The number of separate muscles on the two sides of the body is, according to the ordinary mode of division, upwards of 500. The muscles vary in size, some weighing only grains, and others pounds, as, for example, certain minute muscles in the tympanum of the ear and the vasti muscles of the thigh; in length, they range from two lines to two feet. The form of muscles also varies con-

siderably, according to their position and use; and so likewise does the arrangement of their fasciculi. Usually these latter are disposed longitudinally, but sometimes they form circular bands. On the trunk of the body the muscles are generally broad and flat; in the limbs, on the other hand, they are narrow and elongated—the deep ones, however, being here also broad. Some of the broad muscles are square; others triangular, or lozenge-shaped; and some are indented, or serrated, at their edges; the long muscles are flat and ribbon-shaped, round and fusiform, or, when their fibres are attached obliquely to the sides of a tendon, either penniform or semi-penniform. For the most part, the muscles are attached by both their extremities to the bones, either directly, or indirectly by means of the white, flexible, but inelastic cords, called tendons; but sometimes they are attached to bone by one extremity only, the other being fixed to the skin, or some other soft part, as, *e.g.*, certain of the muscles of the face, and those of the eye-ball. Sometimes a muscle has no connection with bone whatever, as the little muscle in the palm (palmaris brevis), and the orbicularis muscle which surrounds the mouth. In the case of a muscle attached to bone by one end only, that attachment is called its origin, the other being termed its insertion; in the case of muscles attached at both ends to the bones, that attachment which is nearer to the centre of the body, and which is also usually the more fixed point, is called the *origin*, whilst the more distant, usually the more movable, attachment, is named the *insertion.* Muscles may have two points of origin, or heads (biceps of the arm), or three (triceps), or many (great serratus); and, again, some muscles have more than one point of insertion (flexors of the fingers and toes). Muscles sometimes pass from bone to bone, over only one joint (deltoid), but often they pass over two (biceps), or more joints (flexors of fingers and toes, and long muscles of trunk). Tendons of origin of muscles, that is, tendons by which they arise, are usually broad; whilst tendons of insertion are generally long and roundish. The tendons of origin enable a large number of muscular fibres to act from a given point of the skeleton; whilst the tendons of insertion transmit the muscular force to some other, and equally precise, point of bone; hence, they are inextensible, and inelastic. By means of the tendons, also, the muscular force is more conveniently reflected over the joints, or other parts of the skeleton, than could be effected by the tender sensitive muscle itself; in this case, the tendons often run in

grooves in the bones, lined by cartilage. It is, furthermore, obvious that by the use of tendons, as extensions of the muscles, economy of muscular tissue, and lightness and elegance of form around the joints, are secured. In certain broad muscles, however (gluteus, great serratus), the muscular fibres arise, at least in part, directly from the periosteal covering of the bones.

In undergoing contraction, muscles which are connected only with soft parts, simply constrict or tighten those parts. Muscles which are attached by one end to bone, and by the other to soft tissues, exercise a direct traction upon those parts, moving them in accordance with their mechanical arrangements. The tendon of the superior oblique muscle of the eye-ball passes through a loop, which resembles a pulley, the tendon being reflected in a new direction beyond it, so that the movement impressed upon the eye-ball is at an angle with the line of direction of the contracting muscle. When muscles are attached by both ends to bones, their action is after the manner of the so-called levers of mechanics; and either the efficient action of the muscle may be exerted in the line of direction of its fibres and tendons; or, by the reflexion of its tendon of insertion over some bony point, its force may be exerted at a certain angle from its own direction. It is important also to notice that the tendons of insertion, and sometimes also the tendons of origin, are attached to special eminences of the bones, called *processes;* in which case, a muscle acts at an advantage, because its force ultimately operates, from or on to the bone, in a line more or less perpendicular to the osseous surface, instead of in a line nearly parallel with it, as would happen if the surface of the bone were flat, instead of being so elevated. Muscles which pass over the back of a joint, are usually called extensors, because they serve to stretch, or extend, the part beyond the joint; whilst those lying in front of the joint are, for the opposite reason, called its flexors. Other sets of muscles are known as pronators, supinators, rotators, or levators and depressors, according to their respective uses. The names of many muscles are derived from the number of their divisions, their shape, position, points of origin and insertion, or from the direction of their fibres. In certain cases, a single muscle will contract to perform a given action, as in the raising of the upper eye-lid: sometimes two or three are called into action together, as in extending the fore-arm at the elbow-joint

(triceps, anconeus), or in flexing the same (biceps, brachialis anticus, supinator longus); but on the other hand, much more commonly, many muscles concur in the production of a single act; and, indeed, indirectly, nearly every muscle of the body is employed in most movements, either in fixing some parts of the skeleton, or in moving other parts.

The *rapidity* of action of any given muscle, depends directly on the length of its fibres, for the period of contraction is practically the same in long or short muscles, the fibres of one of which may be twelve, and of the other only three inches in length; and, therefore, the amount of contraction in them, in a given time, will be as four to one. On the other hand, the *power* of contraction, or the force, of a muscle, is in proportion to the number of its fibres; and hence, in all the most powerful muscles, the fibres are very short, but so arranged on the tendons as to be very numerous. Notwithstanding the perfection of these, and other more mechanical, arrangements in the body, it happens always, in its more important movements, that there is a disproportionate expenditure of actual muscular power, in comparison with the useful work accomplished. This is well illustrated in the effort required to maintain the position of standing on one leg.

Mechanics of the Body.

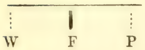
Under this head, we may consider, generally, the distribution of weight in the body, or its *centre of gravity*, its *basis of support*, and the nature of the *levers* employed in the movements of its several parts.

The entire body, being comparable to any other solid mass having certain cubical contents, must have its *centre of gravity* placed at the point of intersection of its three planes—the median-vertical, the antero-posterior vertical, and the horizontal plane, determined by reference to its weight. Of these planes, the median-vertical, of course, corresponds with the median plane of the body, and may be found approximately by a plummet line, when the body is in an erect position; the horizontal plane is found by balancing a man, lying with the arms by his sides, upon a plank, which is supported on a transverse knife-edge; and lastly, the antero-posterior plane is determined by a corresponding method. The point of intersection of these planes, or the normal centre of gravity, when the arms are hanging down by the sides, is generally

said to lie in the cavity of the pelvis, a little in front of, and above, the lumbo-sacral articulation; but, by Weber, it is said to be in the promontory of the sacrum, and, by Meyer, in the vertebral canal, opposite the second sacral vertebra. The slightest displacement of the head, or inclination of the body, a swinging or lateral elevation of either arm, or even stooping, changes, temporarily, the position of what may be called the symmetrical centre of gravity, which of course shifts its situation in the direction of any partial displacement of the movable portions of the frame. The centre of gravity of the head and trunk together, in the sitting position, is midway between the point of the sternum and the vertebral column; and the centre of gravity of the head alone, is opposite a point, above, and anterior to, the opening of the external ear. Elaborate observations have also been made as to the position of the centres of gravity of the upper and lower limbs, and of each separate section of the same.

The *basis of support* of the body, necessarily varies in the recumbent, standing, and sitting posture. As in the case of other solid masses, when the centre of gravity is so placed, that a line, let fall perpendicularly from it, strikes within that base, the equilibrium of the body is easily maintained; but when such a line falls beyond the base of support, the equilibrium of the body becomes unstable, and the body has a tendency to fall down.

1.



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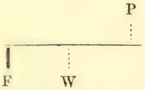

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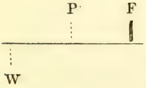


The *levers* employed in the body, are the three ordinary levers known in mechanics. A lever consists of a *rigid rod*, movable in one plane, around a point in the rod, called the *fulcrum*. In actual practice, this fulcrum is seated opposite the point of support; a *weight* or resistance also exists, which has to be moved or overcome; and lastly, there is a force or *power* to move the weight, or overcome the resistance. The three kinds of levers are distinguished from each other, by the relative positions in them of the fulcrum, the weight, and the power. In the *first* kind, 1, the fulcrum F is placed between the weight W and the power P: it is employed in the balance, in working a pump-handle, and in raising the coals in a grate with the poker. The *second*, 2, has the weight W placed

between the fulcrum F and the power P: it is used in raising a weight by putting a crowbar underneath it, and also in wheeling a wheel-barrow. In the *third* kind, 3, the power P is placed between the fulcrum F and the weight W: it is used in the foot-piece of a lathe, and in drawing a ladder from the wall, by pulling on one of the steps near the bottom, whilst the foot is placed to prevent its slipping out. Fire-tongs and sugar-tongs are double levers of the third kind. On comparing the three kinds of levers, it will be seen that the terms on each side, are twice repeated; but that the middle terms consist, respectively, of the three important elements of the lever, arranged in methodical order, viz. in the first kind, the fulcrum F, or point of support, is in the middle space; in the second kind, the weight W; and in the third kind, the moving power P.

In the body, the fulcra are sometimes in the joints, and sometimes at the extremity of a limb, in contact with the

Fig. 48.

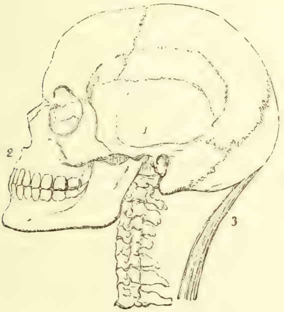


Fig. 48. Example, from the body, of a lever of the first order, shown in the balance of the head on the top of the vertebral column. 1, position of the fulcrum, at the articulation of the cranium with the first cervical vertebra; 2, the weight, or excess of weight, in the fore part of the head and face; 3, the power, in the muscles at the back of the neck.

ground, or with some external point of resistance. The bones constitute the rigid rods, and, with the parts attached to them, the weight to be moved. The muscles are the source of the power. The first kind of lever is illustrated in the adjustment and movement of the skull upon the first vertebra of the neck,

fig. 48; the fulcrum, 1, here being in the transverse plane of the two articular surfaces of the atlas; the weight, 2, is the excess in gravity of the parts of the head and face in front of the joint, over the weight of the parts behind it; whilst the power, 3, resides in the muscles at the back of the neck, extending from the spine to the cranium. The movements of all the vertebræ on one another, from above downwards; the movements of the lowest lumbar vertebra on the sacrum; of the pelvis on the thigh bones; of the thigh on the leg; and of the leg on the ankle, are also examples of the first kind of leverage; so also is the extension of most of the joints in the limbs, as the elbow, knee, ankle-joint, and knuckles of the fingers and toes. The second kind of lever is illustrated in the foot, whilst it rests upon the ground with the heel raised, fig. 49; here the fulcrum,

Fig. 49.

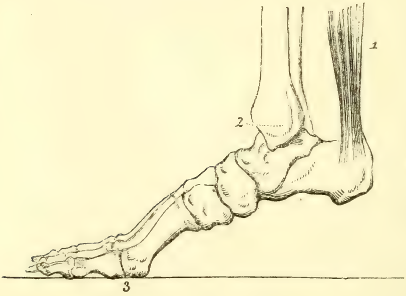


Fig. 49. Example of a lever of the second order, shown in the lifting of the body, by raising the heel from the ground. 1, the power, in the muscles of the calf; 2, the weight of the body transmitted through the leg bones to the foot; 3, the fulcrum, at the ball of the great toe, where it rests on the ground.

3, is the ground or floor beneath the ball of the great toe; the weight, 2, is that of the body transmitted through the leg; whilst the power, 1, resides in the muscles of the calf, which pull by the great tendo Achillis on the heel bone. The depression of the lower jaw, in opening the mouth wide, affords another illustration of this kind of lever. The third kind of lever, which is much more frequently used in animal mechanics, is employed in raising the lower jaw, in moving the

ribs, in raising the collar-bone and shoulder; and especially in the flexion of all the joints of the limbs. The most familiar example is in the elbow-joint, fig. 50; here the fulcrum, 1, is in the joint; the weight, 3, is the fore-arm and hand, without, or with, some additional object in the latter; whilst the power is in the biceps, 2, and brachialis muscles, which are inserted, respectively, into the radius and ulna, in front of the centre of the motion in the joint.

The relative advantages or disadvantages of the several levers, mechanically considered, depend upon the proportionate distances, in each case, between the fulcrum and the weight on

Fig. 50.

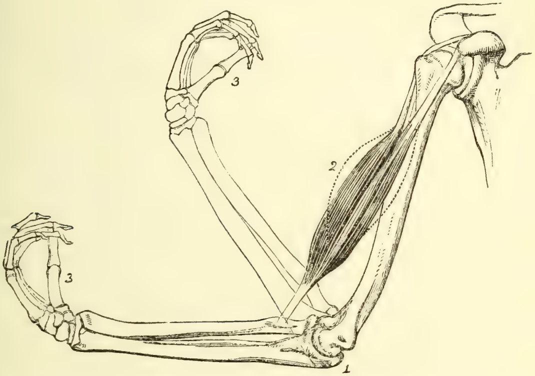


Fig. 50. Example of a lever of the third order, exhibited, in raising the hand, by bending the elbow; 1, the fulcrum, situated at the centre of motion in the elbow-joint; 2, the power, partly resident in the biceps muscle, which is fixed to the radius: the two heads of this muscle are shown, and the dotted lines indicate the shape of the contracted muscle: (the brachialis muscle is omitted); 3, 3, the weight resident in the fore-arm and hand, which are shown in two positions, that is, before, and after, being raised by the contraction of the muscles.

the one hand, and the fulcrum and the power on the other. The distance from the fulcrum to the weight, gives the length of the *weight-arm* of the lever; whilst the distance from the fulcrum to the power, gives the length of the *power-arm*. When the weight-arm and the power-arm are equal in length, the power to balance, or counteract, the weight, must be equal to the weight, and the slightest excess will overcome its resistance,

or move it. When, on the contrary, the power-arm is longer than the weight-arm, then the power needed to balance, and to overcome, the weight, is proportionally so much less. Lastly, when the power-arm is shorter than the weight-arm, the power necessary to balance, or move, the weight, becomes proportionally so much greater. Conversely, when an advantage is gained by a particular lever in regard to *power*, there is a proportionate loss in reference to the *velocity* of movement in the weight; for, though when the power-arm and weight-arm are equal in length, the velocities of the power and weight are equal; yet when the power-arm is longer than the weight-arm, and there is a gain in regard to the useful force exerted by the power, there is a loss in the velocity of the weight, which moves through a smaller space than the power; and again, when the power-arm is shorter than the weight-arm, in which case there is a loss of power, there is a corresponding gain in the relative velocity of the weight, as compared with that of the power.

In the first kind of lever, the lengths of the weight-arm and of the power-arm may either be equal, or may vary in either direction; but in this respect, there is practically, in the human body, a tolerable equality between them. In the second kind of lever, however, there is, necessarily, always an advantage of length on the side of the power, subject to an equivalent loss in velocity; and it is remarkable that almost the only instance in which this lever is employed in the body, is where great force is needed, viz. in lifting the body by raising the heel from the ground; for then the whole weight of the body has to be lifted on one limb, as in the alternate steps in the act of walking. In the third kind of lever, the power necessarily acts always at a disadvantage, accompanied, however, by an invariable gain in velocity on the part of the weight; and hence a moderate amount of contraction in the biceps of the arm, for example, see fig. 50, moves the hand at the end of the fore-arm, through a relatively large extent of space. The gain in velocity, numerically estimated, is exactly proportionate to the length of the weight-arm of the lever, as compared with that of the power-arm; in other words, to the distance between the fulcrum and the weight, as compared with the distance between the fulcrum and the power. If, for example, the latter distance be one inch, and the former ten, then a contraction of the muscle to the extent of one inch, will move the former through ten inches of space.

A force acting perpendicularly on the arm of a lever, operates the most advantageously; hence, in the case of muscles acting obliquely, a loss of power necessarily occurs, so that they require to be proportionally increased in the number of their fibres, which gives them greater power. Speaking generally, the flexors act more favourably than the extensors, and most advantageously, as they approach the utmost limits of their contraction. In the extensors, moreover, the power at all times acts obliquely; hence they are larger, or more bulky, than the flexors, in the ratio of eleven to five.

In comparing the mechanism of the various movements of the body, with that of ordinary levers, it is important to note the fact, generally overlooked, that, in the living body, the power exerted is intrinsic, instead of being extrinsic, or applied from without, as in the common levers. The animal mechanism presents, indeed, examples of the exercise of what are called, in mechanics, *intrinsic forces*. The application of such a force to a lever, so as to produce motion in that lever, necessitates a hinge-like action at the fulcrum, and sometimes even at the seat of the weight, otherwise no motion could take place. Moreover, the production of this internal motion involves a loss of actual lifting force, acting on the weight; lastly, there is not, as in the use of extrinsic forces, any part of the weight supported from without. For these reasons, a much larger amount of muscular power has to be provided for, in the intrinsic exercise of force within the body, than if the force employed were extrinsic, or were applied from without.

External resisting Media.—Forms of progression.

The locomotive acts of man and animals, are influenced by the media upon, or in, which they move, and their whole organisation is modified and adapted accordingly. Thus, we observe progression upon the surfaces of solid bodies, performed either in air or in water; progression upon water in air; progression in water; and lastly, progression in the air alone; but locomotion on solids, locomotion on or in water, and locomotion in the air, constitute the chief forms of progression.

In ordinary locomotion upon *solids*, the weight of a man or animal is supported on those bodies; and in moving upon them, the centre of gravity of the living animal is invariably raised from the base of support, as it is moved onwards, and

then descends again, so as to describe a curved line. The muscular force necessary to move the animal, operating through the lever-like bones, impinges on the solid basis of support; and, as this is assumed, in the simplest case, to be practically immovable, the force exerted acts upon the animal itself, and so lifts it, and moves it onwards in space. Supposing the base of support to be more or less yielding, as in the case of soft ground, or of the flexible twig of a tree, then a certain amount of the force exerted by the animal, is lost in disturbing the basis of support, a part only being left to accomplish the movement of the animal.

In progression upon a solid body, performed *under water*, the same principles are involved; but the muscular effort required to lift the centre of gravity of the animal, is much less than in locomotion upon a solid support in the air; because the weight of the animal is partially sustained by the hydrostatic pressure of the water; and only that part of its weight, which is in excess of the weight of an equal bulk of water, has to be lifted up from the base of support. At the same time, the surrounding medium being heavier than air, a greater resistance is offered to any onward movement; a condition which more than neutralises the advantage just named, and which renders it more difficult to move rapidly at the bottom of a river, than to run in the air.

In progression *upon a fluid*, as in the case of a swimming bird, the conditions of support are those of partially submerged or floating bodies, and are quite peculiar. The weight of the animal is entirely supported by the displacement of a quantity of water of equal weight; and no effort on the part of the animal is necessary to sustain it above its base of support. All its power is, therefore, free to be exerted in progressive movement, which, however, is performed at a disadvantage; first, because of the resistance offered by the displaced water to the submerged part of the body; and, secondly, and this is more important, on account of the imperfect stability of the medium against which the muscular force acts, for a very large part of that force operates merely in putting that medium into partial motion, whilst only a small portion acts, or rather reacts, from the imperfectly resisting medium, to set the body of the animal in motion through it. Hence, the movement of an animal upon water, can never be so rapid as the movements of certain animals over the land.

In progression *in water*, the weight of the animal, as in the

case of fish, is mainly supported by the equal hydrostatic pressure of that medium; and only that smaller portion of weight, which is in excess of the weight of its own bulk of water, operates so as to make it descend in that fluid. Accordingly, a very small proportion of the muscular power exerted is absorbed in the effort to sustain, or lift, the centre of gravity; whilst by far the larger proportion of that force can be employed in the progressive movement. The mode in which that force is exerted upon the water behind the animal, so as to overcome the resistance of that fluid in front of it, will be explained in speaking of the swimming of fish.

In flight, or progression *through the air*, the resistance of the medium in which the animal moves, is reduced to its lowest possible degree, air being proportionally so light and elastic. But the difficulty of moving in it is thereby greatly increased; for almost the entire weight of the animal's body has to be raised from the earth, against its gravity, only so much of that weight being supported by the air, as is equal to the weight of an equal bulk of air, i. e. an almost inappreciable quantity. In this kind of movement, therefore, the principal object to be attained by a bird, for example, is to lift and sustain its weight in the air; the progressive movement forward, being the result of the co-operation of the gravity of the animal acting downwards, and the lifting power acting upwards and forwards. The feeble resistance of the air to the movement of the bird, is more than counterbalanced by its imperfect character as a medium for support, and for the development of that reaction which is necessary for the ascensive and progressive movements of an animal in it. The manner in which, by special contrivances, this reactionary force is obtained, will be described under the head of flight in birds.

On comparing the three chief modes of progression, it appears that less force is needed in the fish moving in water, than in the quadruped moving over land, and less in the latter than in the bird moving through the air. Nevertheless, it is a good illustration of the perfection of the mechanical and physiological adaptations of animals, to find that the velocity attainable by certain birds is greater than that attained by any quadruped or fish; the rate of movement of the hawk is said to be 150 miles per hour; that of the swiftest race-horse, Eclipse, 56 miles per hour; and that of the salmon 20 or 25 miles per hour. The quick walking pace of man is about 5 miles, and his running pace about 10 miles per hour.

Locomotion of Man on Solids.

The only position of the human body, in which the muscles are entirely passive and relaxed, is the *recumbent* posture; the respiratory muscles in that case being alone necessarily in action. In *raising the body* from such a position, the lower limbs are usually drawn up; the heels are planted on the supporting surface, to offer a steady basis of support; one or both upper limbs are put forward, to assist in balancing the trunk upon the tuberosities of the ischial bones, an act which is partly performed by the muscles which pass from the thigh to the pelvis and vertebral column; the vertebral column itself is maintained in position by the powerful muscles of the abdomen, acting from the pelvis upwards upon the ribs; and lastly, the head is supported forwards upon the trunk, chiefly by the action of the sterno-mastoid muscles.

In the *sitting* posture, as upon a chair (and also in that upon the ground), the weight of the trunk is supported upon the tuberosities of the ischia, and not upon the lower end of the vertebral column or coccyx; but, in this attitude, the weight is partly balanced, and supported, by the thighs resting upon the chair, whilst the feet, touching the ground, serve to steady the thighs.

In *rising* from such a posture to the *erect* attitude, the relative positions of the base of support, and of the centre of gravity, are instinctively adjusted, so as to economise, as much as possible, the muscular force. The body has, in fact, now to be supported upon the comparatively narrow base of the two feet; whilst its centre of gravity has to be elevated in the air, by the additional length of the thigh bones. Accordingly, when we rise from a chair, we draw backwards one or both feet close to, or even beneath, the chair, and then incline the body forwards, so as to bring its weight as much as possible over the future base of support; when, by the contraction of the muscles of the calf, acting from below, the leg bones are brought into a vertical position over the ankle-joints; by the muscles in front of the thighs, acting from the patellæ, the thighs are drawn into a vertical position upon the legs; by the muscles at the back of the thighs, and by the great glutei and other muscles at the back of the pelvis, this latter part of the skeleton, together with the trunk generally, is rolled backwards, and so erected upon the heads of the thigh bones;

by the muscles of the back, the vertebral column is drawn into the upright posture; and lastly, by the muscles at the back of the neck, the head is supported upon the vertebral column, with the face directed forwards. In this action, then, of rising from the sitting posture, the several angles between the foot and leg, the leg and thigh, and the thigh and trunk, are opened out; and the body assumes its extreme length.

The erect posture, the characteristic attitude of man, is therefore by no means a passive, but essentially an active, attitude; and, though not locomotive, in reference to the base of support, is really a locomotive act in reference to vertical space above the base of support. It requires, indeed, the active and energetic employment of a multitude of muscles, not only to assume it, but also to maintain it, as is well illustrated by the facts, that children are unable to stand until after many trials, and that adults stumble, or fall, when the nervous power, which commands or controls the muscles, is lessened or suspended, as in drunkenness, apoplectic seizures, fainting, or sudden suffocation; in which cases, the body, with its system of internal movable levers, the bones, doubles at its various angles, collapses, and falls to the ground. Nevertheless, we find on examination, that these bones are admirably constructed, and shaped for supporting their own weight, and the weight of the parts attached to them, in the erect position, every portion of the skeleton, affording directly, or indirectly, evidences of design in its adaptation to that posture (see figs. 1, 2).

Thus the human *foot*, from its great breadth, the flatness of the toes, and the parallel arrangement of the metatarsal bones, figs. 51, 52, is admirably adapted for the support of weight. The foot, moreover, forms a strong double arch. The chief arch, fig. 52, from before backwards, passes from the broad os calcis, or heel bone, 2, through the astragalus, 1, and other bones of the tarsus, 4, 6, 7, and metatarsus, 8, as far forward as the balls of the toes, the chief support in front, however, being in the ball of the great toe.* The extension of the phalanges of the toes, 9, 10, 11, forwards, from this arch, serves to increase the length of the foot, for the purposes of holding on to uneven surfaces, and of more effectually raising the body over the foot and propelling it forwards in the act of walking or running; besides this, they impart elasticity to the step. The lateral arching of the foot occurs in the middle and anterior parts of the tarsus, and in the posterior

and middle portions of the metatarsus; it contributes greatly to the strength of this part of the frame, which has at every step to bear the whole weight of the body. The marked projection of the heel, 2, gives a great advantage in leverage to the large muscles of the calf. The arching of the foot likewise

Fig. 51.

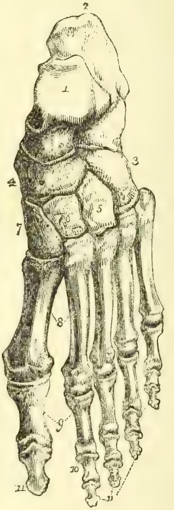


Fig. 51. Dorsal or upper view of the bones of the left foot, showing its great strength, breadth, the parallel arrangement of all the toes, and the great size of the innermost toe. 1 to 7, the tarsal bones, or tarsus; 1, astragalus; 2, os calcis, calcaneum or heel bone; 3, cuboid bone: 4, scaphoid bone; 5, 6, 7, the three cuneiform bones; 8, the five metatarsal bones; 9, 10, 11, the first, second, and third rows of phalanges.

Fig. 52.

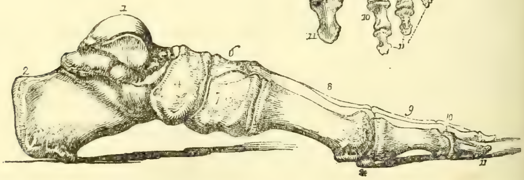


Fig. 52. Internal lateral view of the bones of the foot, showing the strength of the tarsal bones, and of the metatarsal bone of the great toe, the projection of the heel bone, and the antero-lateral arch of the foot. 1 to 7, the tarsus; 1, astragalus; 2, os calcis; 4, scaphoid bone; 6, 7, two of the cuneiform bones; 8, the metatarsal bones; 9, 10, 11, the three rows of phalanges of the toes; * sesamoid bones at the ball of the great toe.

assists in protecting the important soft parts, namely, the muscles, bloodvessels, and nerves, which are situated beneath it. The bones of the foot are not merely so shaped as to fit together in the form of an arch, like the key-stones in masonry, but they are maintained in that position by strong ligamentous

bands, passing either between or across the under surfaces of the bones; the short muscles of the foot also contribute to maintain its arch-like form (see fig. 4), and even the strong plantar fascia, with its great thickness of fibres, serves not only to protect the soft parts covered by it from injury through the sole, but also contributes to maintain the antero-posterior arch of the foot. Thus constructed, the arch of the foot, strong, and yet elastic, from the gliding movements of its joints, and possessing likewise, without diminution of its strength, a slight lateral motion, at the ball and socket joint, between the astragalus and the scaphoid, is capable of adapting itself readily to the unevenness of the surfaces on which we tread, and also of breaking the shock produced in walking, running, leaping, or other movements of the body.

At the *ankle*, the superincumbent weight of the body is borne upon the broad square surface of its topmost bone, the astragalus, fig. 52, 1, from which the weight is transmitted in the standing posture, partly backwards through the os calcis, 2, and partly forwards through the other tarsal, 6, 7, and metatarsal bones, 8. The surface of the astragalus is received into the deep quadrangular recess formed by the lower end of the tibia, the inner ankle, or malleolar process of that bone, and the outer ankle, or malleolar projection of the fibula. With the exception of a slight lateral play, which is very limited when the leg is at right angles to the foot, but is somewhat more free when the foot is fully extended, giving a graceful turn to the limb, the chief movement here permitted is of a hinge-like character, in which the tibia, or main bone of the leg, may be said to rock backwards and forwards upon the astragalus.

At the *knee-joint*, the femur can be brought, in standing, in a straight line over the tibia, so that the one bone is supported on the other, like a pillar. The chief points of constructive adaptation here, are the very broad and slightly hollowed surfaces of the upper end of the tibia, the concave semi-lunar cartilages which deepen the bearing surface of the joint, the large expanded condyles of the femur, the strong lateral ligaments, and the still stronger internal crucial ligaments, both sets being attached behind the axis of motion; and lastly, the protective influence of the patella in front, and also the increased leverage given to the muscles fixed to that bone. The knee-joint, indeed, is the largest in the body, and, from its breadth and strength, is admirably

suited to bear the weight, and sustain the shocks, which are continually brought to act upon it. One point, specially noticeable, is the greater length of the inner condyle of the femur as compared with the outer condyle—a formation necessary to establish a *horizontal* line of support, from side to side, between the femur and tibia, at the knee-joint. At the upper end of the femur, the neck is elongated, and placed at an angle with the shaft, so as to increase the breadth of the body for the attachment of muscles at the hips; and in consequence of this, the thigh bones incline towards each other from the pelvis to the knees, so that the leg and foot may be brought more directly beneath the centre of gravity. If, with this inclination inwards of the thigh bone, its condyles had been of equal length, there would either have been a certain interval between the internal condyle and the head of the tibia, or, if the tibia had been elevated at that edge to meet the femur, the bearing surface of the knee-joint would have formed an inclined plane downwards and outwards, and so would have presented a condition of constant insecurity. The great relative strength, and length, of the human femur, are also associated with the firmness of posture, and the rate of locomotion, of man.

At the *hip-joint*, the depth of the acetabulum, especially the overhanging of its upper border, the increased protection afforded by its fibrous rim, the presence of the internal ligament (ligamentum teres), and of the strong accessory ligament over the front of the joint, give great security to this part of the frame; whilst the slightly arched form of the femur, the accumulation of compact bony tissue at the back of this bone, and, we may also add, the prismatic shape of the tibia, and the brace-like provision afforded by the presence of a complete fibula, are evidences of special adaptation in the supporting osseous columns of the lower limb.

The strong hoop-like mass of bone formed by the *pelvis*, is adapted for the steady support of the superincumbent weight of the rest of the trunk, and for the transmission of this, downwards to the thighs; its circular form imparts to it great strength; its inclined position from before backwards, serves to sustain the viscera within it; and the greater thickness of its bony tissue along the lines extending on each side outwards and downwards from the sacrum to the upper part of the acetabula, insures sufficient strength in the directions through which the weight is transmitted from the lower part

of the vertebral column to the two hip-joints, and thence to the heads of the thigh bones. The large and projecting surfaces of the pelvis are occupied entirely by muscular attachments, and they afford great leverage for those muscles which pass upwards from the lower limbs, and serve to balance the pelvis upon the thighs.

The great size of the upper part of the sacrum, and its mode of attachment between the innominate bones, the breadth and mass of the bodies of the lumbar vertebræ, the gradually diminishing size of these, and of the dorsal and cervical vertebræ, in passing from below upwards, in accordance with the successively diminished weight which they have to bear, are arrangements evidently in harmony with the erect position of the body (see figs. 10, 11, 12). The length and breadth of the spinous processes correspond, severally, with the strength of the muscles connected with them at different parts of the spine, serving to increase their leverage and their surfaces of attachment. Moreover, the direction of these, as well as of the transverse processes, is horizontal in the loins and neck, so as to permit of rotatory movements in those regions; whilst, in the back, the spinous processes overlap each other, and the transverse processes are so connected with the ribs, as to impede such rotation, whereas they do not prevent extreme forward bending in that part of the vertebral column. In the neck and loins, the bending of the column takes place chiefly in the backward direction. The presence of the inter-vertebral substances, figs. 10, 12, and their effect in imparting elasticity and diminishing shock, have already been noticed. Lastly, the curvatures of the spinal column itself, presenting an anterior convexity in the neck, a posterior convexity in the back, and, again, an anterior convexity in the lumbar region, also increase the elasticity of the vertebral column, and diminish the effects of concussion, the lines of force passing out through various parts of a curve, instead of being continued throughout the whole length of a straight line. The several curves of the spine are, moreover, so adjusted, that, in the erect posture, a perpendicular line from the summit of the movable part of the vertebral column, would fall through the centre of its base.

The peculiar mode of adjustment of the head upon the trunk, fig. 12, also affords proof of the special adaptability of man to the erect position; for the foramen magnum of the *occipital* bone, is placed farther forward in the base of the

skull than in the vertebrate animals generally, showing a special fitness for the support of the head upon a vertical or upright vertebral column, instead of at the end of a vertebral column more or less inclined towards the horizon. In man, the foramen magnum is placed a little behind the centre of the skull, which is, therefore, not quite exactly balanced, but exhibits a slight tendency to incline forwards, when muscular effort is relaxed from fatigue, fainting, or sleep. The absence of prominent ridges on the cranial surface, also indicates that its supporting muscles do not require the advantages of leverage, which they usually possess in animals; the shortness of the cervical spines, and the want of a ligamentum nuchæ, are facts having a like bearing. The position of the mouth, and of the several organs of the senses, especially of the eyes, in relation to the wants of man, also demonstrates his fitness for the upright posture.

Finally, the absolute unfitness of the upper limb, if examined from its single point of bony support at the inner end of the collar-bone to the tips of the fingers, whether considered as regards its position, length, size, shape, or the structure of its several parts, for bearing any share of the weight of the body, affords a negative argument in favour of the intended erect attitude of man.

Thus constructed, and adapted for the erect position, the entire body may be regarded as composed of five chief segments, the lowest being formed by the arched foot, the next above that by the legs, and the others in succession by the thighs, the trunk, and the head. Now, the foot affords a base of support to the rest, and, when naked, can grasp the ground by aid of the flexor muscles of the toes. The weight is supported chiefly on three points, viz., the heel, and the anterior ends, or heads, of the first and fifth metatarsal bones. In standing on the toes, with the heel raised, the weight is borne on the ends of all the metatarsal bones generally. Opera-dancers, however, by practice, are able to sustain the weight on the end of the great toe. The next segment of the body, the leg, is balanced on the foot, partly by the extensor and flexor muscles of the leg (see figs. 4, 5), in front and behind, acting as opponents to each other, but, mainly, by an instinctive adjustment of the centre of gravity over the vertical axis of the tibia. The thigh is similarly balanced upon the leg, also, by extensor and flexor muscles; and the pelvis and trunk upon the thigh, by very numerous and large muscles, such as

the glutæal, adductor, iliac, and psoas muscles. The spine itself is kept erect by the powerful erectores spinæ muscles, aided, however, by many others. Lastly, the head is balanced on the neck by the complexi, splenii, sternomastoidei, and other deeper muscles. At the knee-joint, the crucial ligaments are stretched, as the thigh assumes the vertical position over the legs; they thus retain those bones in apposition, like a rigid pillar, with little or no muscular effort. The ligamentum teres, and the external accessory, or ilio-femoral, ligament in front of the hip-joint (see fig. 1), perform the same office there. The elastic ligaments connecting the arches of the vertebræ behind, economise, as already mentioned, the muscular power of the erector muscles of the spine. The muscles at the back of the neck, are instinctively relieved by a slight inclination of the head backwards, so as to bring the centre of gravity over the basis of support in the vertebral column.

In thus *standing* erect on both legs, the weight of the body is transmitted perpendicularly through the vertebral column; thence, laterally and obliquely, through the sacrum, to the hip-bones; and thence, through the lower limbs, to the ground. In this position, the centre of gravity is placed perpendicularly over the middle of the basis of support, which corresponds with the surface of the ground covered by the feet, and with that forming the interval between them; a line let fall from it passes midway between the inner ankles. The natural slight eversion of the feet, materially increases the mechanical base of support, over which it is easy to maintain the weight of the body. In *standing at ease*, one leg bears nearly all the weight of the body, whilst the other is simply planted, at a little distance forwards, upon the ground; the trunk inclines over the limb which bears the weight, and a line let fall from the centre of gravity, now passes through the middle of the ankle-joint of that foot; the limb being stiffly extended, the ligaments of the knee and hip-joints are so stretched on that side, as to save muscular power. On the opposite side, the pelvis is lowered, the thigh is bent a little upon it, and the leg a little on the thigh; so that the muscles of that leg also thus obtain some rest. In *standing* entirely *on one leg*, a line from the centre of gravity passes through that limb to the ground; and, unlike the position just mentioned, this attitude demands considerable muscular effort, especially to keep the leg and thigh erect upon the ankle and knee, and to balance

the pelvis, which inclines over to the same side, upon the head of the thigh-bone. Standing on one leg soon becomes very fatiguing, not only because the limb has to bear double the usual weight, but because the base of support is so reduced, that more energetic muscular action is needed, in order to keep the centre of gravity in the proper position over it. It has been computed—and it is quoted as an example of the disproportion already mentioned as prevailing between the muscular power expended, and the useful work accomplished—that, in raising the heel, and standing on tip-toe on one foot, the muscles of the calf must develop 80 times more force than would directly counterpoise the weight of the body; so that, if the latter be taken at 150 lbs., the muscles of the calf must exert an effort equal to 12,000 lbs. In the act of walking, as we shall see, the body is partly, and in the act of running, entirely, supported in this way during a certain part of every step.

The act of *walking* is accomplished by means of alternate unsymmetrical movements on the two sides of the body, performed at the ankle, knee, and hip-joint, the trunk being kept, as nearly as possible, in a state of equilibrium, though, as we shall immediately show, its centre of gravity is not merely carried forwards, but undergoes both vertical and lateral oscillations. One leg is first lifted from its base of support, with a slight flexion of the knee and foot, so as to prevent the latter from touching the ground, and is advanced a certain distance, chiefly by swinging, as will be presently mentioned, but also by flexion of the thigh upon the pelvis, and by extension of the leg and foot; it is soon permitted to touch the ground in advance of the body, the centre of gravity at the same time descending a little, as well as advancing forwards, and also inclining over in the direction of the advanced limb. As the forward foot advances, the hinder one inclines in the same direction, and the centre of gravity, now moved beyond the original base of support, is slightly lowered. When the forward foot has touched the ground, the hinder one is raised by extension of the foot, which, continuing to press on the ground, assists in urging the centre of gravity forwards, a little upwards, and still more over to the opposite side. The centre of gravity having now reached a secure point of support, over the advanced and stationary limb, the hinder limb completely leaves the ground; the thigh is slightly bent on the pelvis, the leg is a little bent on the thigh, and the foot somewhat on the

leg; in this position of the segments, it is shortened by about one-ninth part of its length, so that the toes should keep clear of the ground. The limb, in its turn, is now swung forwards, to be planted on the ground in advance of the body, the centre of gravity being again carried forwards, downwards, and over to the same side, and the foot being finally planted on the ground, as before. A repetition of the same movements, with the same results, is performed by the two limbs alternately. Regarding the body as a whole, the centre of gravity is not moved directly forward, at a uniform height from the ground, in any mode of progression. Such a condition does not take place in any living animal, though it happens in the case of inanimate objects, such as carts, locomotives, or masses of matter dragged over horizontal surfaces. In the living body, to advance implies an elevation of the centre of gravity, followed by a slight descent; in other words, the body is lifted and falls at every step forwards, and so describes a vertical oscillation, which has been estimated at about one inch and a quarter in extent. As above shown, lateral oscillations also occur, due to the alternate shiftings of the centre of gravity from a point over one leg to a point over the other. In walking, the advancing foot invariably touches the ground, before the hinder foot is lifted; so that in this mode of progression, there is a short period, during which both limbs touch the ground, alternating with a longer period, in which only one limb rests upon the base of support. The general rate at which man can walk, depends on the length of his lower limbs, the thigh being unusually long. The pace, in particular cases, is regulated by the length of the leg, and by the muscular efforts employed to secure rapidity of step. In rapid walking, almost every muscle of the body is exercised; the duration of the step is shortened, and so also is the length of time during which both feet touch the ground together; the length of the step may be either shortened or increased. In the case of a man, walking at the rate of 4 miles an hour, and whose legs were 34 inches in length, the number of steps taken in 15 minutes was 2,000, the length of each step 2·64 feet, and the period of each step ·45 of a second (Vasey). In very quick walking, the rate has been nearly $5\frac{1}{2}$ miles per hour, or about 7·9 feet per second. It has been shown that, whilst in slow walking, the advancing limb performs as complete an oscillation as its length will permit, and is off the ground for two-thirds of a second, in very quick

walking, and in running, the limb performs only half an oscillation, but in much less time, that is, in less than half a second: again, in slow walking, the supporting limb is in contact with the ground one-third of a second, but, in quickened walking, a shorter and shorter time, until at length, in running, the duration of such contact is only a small fraction of the time in which the other leg is swinging.

To the act of *running*, which, like walking, consists of unsymmetrical movements, there is a transition from rapid walking, in the step known as 'the double.' In true running, which might perhaps be confounded with quick walking, the distinguishing character is that both feet are never on the ground together, the hinder foot being raised a brief interval before the advancing foot comes to the ground; so that in running, there is a short interval, during which one foot only is on the ground, and then a longer interval in which both feet are off the ground, and the body, instead of being alternately propelled, is continuously swung forwards in the air. The centre of gravity not only advances, but oscillates in the same manner as in walking; the curve described in ascending and descending, varies from three-quarters of an inch to an inch and a quarter, and the lateral oscillations are less than in walking, in consequence of the advancing foot being brought more nearly under the middle line of the body. In running, it has been shown that, just as the forward foot reaches the ground, the centre of gravity is exactly over it: an arrangement necessary to counteract the tendency of the body to fall forward, which is very much increased at high velocities; if the foot is prevented advancing, as in the act of tripping, then the person either stumbles or falls. In any increase of pace, whether of walking or running, the mean height of the centre of gravity is often slightly diminished by an increased flexion of the lower limbs, which also increases the possible length of the step. The ordinary rate of quick running is about 10 miles an hour; but, for short distances, the rate may be 13 miles an hour, or about 18·8 feet in a second.

In both walking and running, it has been found that the trunk is inclined forwards from the vertical line at an angle, which gradually increases as the step becomes more rapid. In both progressive movements, too, the lateral disturbance of the centre of gravity, which depends on the alternate forward movement of the lower limbs, drags the pelvis first after one and then after the other limb, and so leads to a rotation of

the trunk. This is compensated for, or counteracted by, a corresponding forward movement of the *opposite* arm, accomplished not by muscular exertion, but by a swinging or pendulum-like action, which serves to restore the balance of the upper part of the trunk. It has likewise been shown by the brothers Weber, to whom we are indebted for most of our knowledge on this subject, that the forward movement of the lower limbs, though guided by the muscles, especially in the maintenance of such a length of the limb and elevation of the toes, as will prevent these from striking the ground, is, mechanically considered, and in the main, a pendulum motion; and that the weight of the limb itself is, in part, supported, as already explained, by the pressure of the atmosphere transmitted to the hip-joint. The full swinging movement of the lower limb, allowance being made for the forward motion, through space, of the acetabulum, or point of suspension, is almost exactly equal to the oscillation of a pendulum of the same length, at the same part of the earth's surface, both in extent and velocity. The economy of muscular power thus obtained, is sufficiently obvious.

In *leaping* from both feet, the muscular acts, unlike those performed in walking and running, are symmetrical on the two sides of the body. The centre of gravity is first lowered considerably, by the bending of the joints of the lower limbs, and by leaning forwards with the trunk; in this position, a line let fall from the centre of gravity, passes down through the balls of the toes, from a point anterior to the sacro-lumbar articulation, in consequence of the forward projection of the head and arms. By the sudden and violent contraction of the extensor muscles of the lower limb, which are much stronger than the flexors, that is, by the powerful action of the muscles of the calf, of those in front of the thigh, and of the gluteal and other muscles at the back of the hip, the more or less acute angles formed at the ankle, knee, and hip, are simultaneously opened, and the centre of gravity is lifted upwards, or upwards and forwards, according to the inclination of the trunk, or to the special direction of the impulse. Leaping consists, therefore, of a series of jerks of the body, produced by single powerful efforts. In leaping, the legs are first drawn after the body, but they soon advance forward to receive the descending weight; and leaping is distinguished from running, in this; that the centre of gravity is raised so high, and for so long, in the air, that the lower limbs are able to complete their forward oscillation, and so accomplish a

very long step or leap. In the combination of leaping with running, the velocity of the body acquired in the former act, is superadded to the impulse of the leap, and so the total length of the spring is increased. The forward impulse of the body is shown by the movement of the arms in alighting. Hopping is performed on similar principles to the leap, but the spring takes place from one leg only.

There are some other movements which need not be particularly described, such as creeping, and climbing, or letting oneself down a rope or tree. Swimming is a special mode of progression, which will be presently noticed.

Locomotion of Animals on Solids.

In the higher Quadrumana, generally, the attitude of the body, in ordinary progression, is semi-erect, and in the very highest, especially in the gorilla, if recent observations be correct, an almost perfectly erect posture and gait can be temporarily maintained, without any support from the anterior limbs. In continuous and rapid progression, however, even this animal leans forward, and shambling along, supports the weight of the fore-part of the body upon its long anterior extremities, touching the ground alternately with the back of the knuckles of one or other hand, and moving therefore in a half-biped, and half-quadruped, mode of progression. Neither in the gorilla, orang, or chimpanzee, does the skeleton exhibit that perfect adaptation to the erect posture which is seen in man. The feet, though entitled, from their function, to the designation of hands, as implied by the title Quadrumana, are, nevertheless, anatomically constructed after the manner of the human foot, and not after the fashion of the hand. But the foot of the ape is far less perfectly adapted to bearing weight than that of man. The tarsus, metatarsus, and phalanges, are proportionally narrower and longer; this narrowness is due partly to the general slenderness of the four outer metatarsal bones and their phalanges, but also to the altered size, position, and form, of the great toe, which ceases to be the largest toe in the member, and is no longer placed parallel with the other toes, but is very much shorter and smaller, stands inwards from the rest, and in these respects, as well as in its form and opposability to the other toes, closely resembles a thumb; in the orang, it ceases to possess a long flexor muscle. Moreover, the os calcis, in most of the apes, is small, less projecting, straight, and somewhat raised from the ground; the arch of the foot is less pronounced, and it is so articulated with the leg, that it is not fairly applied to the ground by the sole, but, more or less, by its outer border. The foot of these creatures, indeed, is not a hand, but rather a grasping or prehensile foot; and, in certain men, this character, as manifested by the slight opposability of the great toe, is not entirely absent. In descending the scale, the foot is still more slender and prehensile, the great toe is further reduced in size, has no independent action, and the foot departs more and more from its human character, ultimately being adapted only for mere *clasping*, as in the spider monkeys. Besides this, in the Quadru-

nana, the bones of the leg are more or less bowed; and in the ordinary osition of the tibia, femur, and trunk, in standing, these segments of he animal's frame, are placed at angles to each other, and do not rest n the form of an erect perpendicular column; the surfaces of the knee oint are comparatively small; and the entire lower limb is not only veaker, but altogether shorter, than in man; whilst the arms are engthened, in various proportions, in different species, so as to enable hem to reach the ground. The pelvis is narrower, longer, and weaker. The vertebral column does not present that marked threefold curve which it has in man: nor do the vertebræ exhibit that gradual increase n size from below upwards, which they present in him. In the gorilla, rang, and chimpanzee, there are only four lumbar vertebræ; the umber of dorsal vertebræ bearing ribs is thirteen in the gorilla, twelve n the orang, and thirteen in the chimpanzee. The surfaces of the odies of the vertebræ generally, are inclined to the horizon; and their pinous processes are more powerfully developed than in man, to nable the posterior or erector muscles to support the habitual forward nclination of the body. These characters of the spines are particularly oticeable in the upper dorsal and lower cervical region, where they fford increased surface of origin, and greater leverage, for the muscles ntended to support the head. The cranium itself has its occipital oramen, and adjoining condyles for articulation with the neck, situated urther and further back, as we descend in the Quadrumanous scale; so hat the weight of the head is carried at a mechanical disadvantage, as ompared with man; a disadvantage counterbalanced by the greater development of the spinous processes, and of the posterior cervical muscles. n the lower Quadrumana, such as the ateles or spider monkey, the ttitude and mode of progression, on the ground, become more decidedly orizontal; the anterior and posterior limbs being now of nearly equal ength, and the hands and feet almost exactly resembling each other in orm. In the lowest, so-called, Quadrumana, as in the Lemurs, the erect, r partially erect, position, is only momentarily possible, and progression n that attitude never takes place; the great toe ranges with the others, nd bears a claw.

In the Anthropoid apes, the centre of gravity is placed higher up in he trunk than in man, owing to the comparative shortness of the hinder imbs, and the greater proportionate length of the anterior ones, as well s to the forward inclination of the trunk. In the lower Quadrumana, he centre of gravity advances still further forwards, approaching its ormal position in the quadruped.

In the Quadruped mode of standing and locomotion, the intrinsic power s, as usual, obtained by muscular force, exerted upon movable levers, aving their points of support and resistance upon the ground. Their rogressive motion is compounded of the results of muscular force and gravity. Owing to the near approximation, in length, between the fore nd hind limbs, and to the larger development and greater length of the eck and facial part of the head, to which the prehensile functions are ow transferred, the centre of gravity of the whole body is advanced forwards, and is placed somewhere about the middle of the thorax, a little ehind the junction of the fore-limbs with the trunk. It is mainly in onsequence of this forward position of the chief mass of the body, that s, of its centre of gravity, that a quadruped animal experiences such

difficulty in the act of rearing, and cannot long maintain that position. The size of the muscles of the hinder limb, the nature of its joints, the angular position of its segments, and the narrowness of its base of support at its extremity, also occasion this difficulty; whilst the mechanism of the vertebral column, the absence of that gradual increase in size of the bodies of the vertebræ from the neck to the lumbar region, the comparative small amount of intervertebral substance, and other peculiarities, such as the absence of the triple vertebral curve, and the relative size of the pelvic and spinal muscles, display a want of adaptation for the erect posture, and a fitness of the trunk for the horizontal attitude. The position of the head at the end of the neck, and the development of the dorsal and cervical spinous processes, also show an express adaptation to this horizontal position. The trunk of the body, especially its thoracic part, is now compressed from side to side; and the anterior limbs are attached near together on the under side of the trunk, the weight of the fore-part of which is thus more easily supported. The hinder limbs are moderately thrown out above at the pelvis, but are also inclined towards each other where they reach the ground, so as to bring the base of support there also under the weight to be carried.

In *standing*, in the quadruped position, owing to the forward situation of the centre of gravity, a greater amount of weight is carried on the anterior than on the posterior limbs, the weight not being equally divided between them, as might, without consideration, appear to be the case. In the most perfect forms of quadruped *progression*, as, for example, in the active Ruminants (stags, antelopes, &c.), and in the Soliped Pachydermata (horse, zebra, donkey), the fore limbs are brought very near together under the body, there being no collar-bone to thrust them outwards from the sternum; owing to the absence of this bone, moreover, the fore limbs are attached to the trunk by muscles only. The chief muscle is called the great serratus (represented, in the human body, at 5, fig. 4), which, arising by many heads from most of the ribs low down, passes upwards, in the quadruped, towards the scapula, into which it is inserted; by this arrangement on the two sides, the trunk of the animal may be said to be suspended in a sort of muscular sling, composed of the two large serrati muscles, which spring from the thorax, and are attached to the scapula, or upper segment of each anterior limb. The posterior limbs, on the other hand, are connected by articulations with the pelvis, and the pelvis similarly with the vertebral column; so that here the weight of the body is transmitted directly from bone to bone. These differences between the modes of connection of the fore and hind limbs, have reference to the offices of those limbs in progression. The hinder limbs, with their segments inclined more or less at angles to each other, and provided with powerful muscles for unfolding those angles, and so straightening and increasing the length of the limbs, are concerned mainly in giving the forward and upward impulse to the body of the animal over the ground. The anterior limbs, besides assisting in the progressive movements, have also, and chiefly, to receive and check the downward course of the centre of gravity lying in the anterior part of the body; the segments of this limb are, accordingly, straighter, or less angular, than those of the hinder limb.

In the larger and heavier quadrupeds, such as the elephant, rhinoceros,

nd hippopotamus, the segments of the limbs are shorter, thicker, and nore perpendicular in their direction; peculiarities which increase the earing powers of the limbs, but diminish their locomotive capabilities, s manifest in the slower and more unwieldy actions of those bulky reatures. In the Equine, and more active of the Ruminant, animals, he limbs are proportionally more slender, longer, and have the segments laced at more acute angles, especially, as already noticed, in the hinder imb; of these, however, the horse is the best fitted of all quadrupeds or rapid and energetic motion, and for draught, and constitutes the xemplar of quadruped locomotion. The Flying Childers ran at the rate f 4 miles in 6 minutes and 2 seconds, or about 40 miles an hour, whilst he pace of Eclipse was 56 miles an hour, or nearly a mile in a ninute. This swiftness of the horse is mainly owing to the solidity of he extremities of its limbs, which consist of an enlarged and expanded ingle toe, or finger, which carries the broad and solid hoof. In the eavier Pachydermata, the toes are more numerous, being three in the hinoceros, four in the hippopotamus, and in the elephant five, enclosed n one mass; but the foot, though broader for carrying weight, loses in rmness. In the cleft foot of the Ruminants, the number of digits is our, two bearing the proper bisulcate hoof, and two the spurious hoofs; he parts of the foot are thus easily spread out, so as to give a greater hold pon soft ground; but it exhibits a proportionate degree of weakness.

The movements of quadrupeds are named the walk, the amble, the rot, the canter, and the gallop. In the act of *walking*, a quadruped first noves forward one fore-leg, and then the opposite hind-leg; next the ther fore-leg is advanced, and then the opposite hind-leg, and so on; nese several movements being perfectly distinguishable, and following n regular sequence, however rapidly the animal may walk. The centre f gravity not only moves forwards, but rises and falls, and moves bliquely from side to side, according as the one or the other fore-foot is eing advanced; moreover, one foot only is off the ground at the same noment, the advancing fore-foot always being placed down before the pposite hind-foot is raised, and the latter being placed down before the pposite fore-foot is raised. In *trotting*, the fore and hind limbs of the pposite sides, are advanced simultaneously, and they are raised from the round, and placed upon it again, also simultaneously; so that the centre f gravity is supported alternately upon the right fore-leg and left hind-g, and then upon the left fore-leg and right hind-leg; and in this novement, there is much less lateral oscillation, indeed scarcely any at ll, in comparison with the walking movement, as the rider on horseback ractically knows. In *galloping*, both fore-legs are lifted from the round almost simultaneously, and the body of the animal is projected pwards and forwards, by the extension of both hind limbs; the weight f the body then descending, is received on both fore-legs, which are rought to the ground again, almost at the same instant of time, when ne hind-legs are once more brought under the body, and placed almost multaneously upon the ground, so as to be ready for the performance f another spring. *Cantering* is a sort of slow, measured gallop, in hich a longer interval of time elapses between the placing of the two re-legs and the two hind-legs upon the ground. In the canter, one or ther pair of legs only, is raised from the ground at any one instant; so nat the body of the animal is always supported by one or other pair of

limbs; but in the gallop, there is a period, short in the slow gallop, but more and more prolonged in the rapid gallop, as in the active strides of a race-horse, when all four limbs are off the ground, and the animal is swinging in the air.

In the Carnivora, the mode in which the feet are used in progression, has led to a threefold division of that class into the digitigrade, such as the cat and dog tribes; the plantigrade, represented by the bears; and the palmigrade, natatory, or swimming Carnivora, exemplified by the seals.

Amongst the quadruped Mammalia, a well-marked distinction may be drawn, as regards their locomotive powers and habits, between those which possess a clavicle, and those which do not. As already stated, in the larger quadrupeds, moving like the horse, zebra, and donkey, there is no clavicle, as in the rhinoceros, elephant, hippopotamus, hog, ox, giraffe, camel, stag, antelope, goat, sheep, and other Ruminants. In all such animals, it is to be noted that the anterior limb is used exclusively for purposes of locomotion, or for those of offence or defence; but it has no prehensile faculty. In a great number of the four-footed Mammalia, however, the anterior limb has a prehensile character, or is used in some special manner adapted to the habits of the animal, in addition to its mere locomotive function; in such cases, a collar-bone, more or less perfectly developed, is found. Thus, in the Carnivora, in which the anterior limb is used in striking or seizing the prey, a short, imperfect collar-bone is found, which is smaller in the dogs and larger in the cats; in the seal tribe, it is absent. A slender collar-bone exists in certain Rodentia (as the rabbit, hare, and rat), which use their anterior limbs in scraping and burrowing; and in the squirrel, which can climb, seize, and hold nuts and other food in its fore-paws, the clavicle is well developed. In the Cheiroptera (bats) the anterior limbs are organised for flight, and also have a clavicle, which is long, strong, and bent. This bone is likewise present, and strongly developed, in the burrowing Insectivora, being short, broad, and cubical in the mole; it is also large in the Edentata (armadillo, ant-eater). Even in the low Marsupials (as the kangaroo), which have considerable prehensile power in their comparatively small fore-limbs, the clavicle is present. In this creature, the quadruped mode of progression is only occasionally employed; but its more active movements consist of powerful leaps, which it performs by the sudden extension of its large hinder limbs, and by the flexion of its powerful tail, the muscles of both of which parts are enormously developed; there is a sharp claw on the large fourth toe, which is used to tear open the flank of an attacking animal. With the kangaroo, a very common attitude is a semi-erect position, maintained by resting upon the hinder limbs and tail. The squirrel, likewise, uses its large bushy tail, both as an organ of support in sitting and also in leaping.

A still further deviation from the ordinary mode of progression on land, in Mammalia, is witnessed in the seals, which animals, when out o the water and moving over the ground, accomplish this, partly by a feebl and awkward motion of the anterior paddle-like limbs, and partly by a wriggling motion of the hinder portion of the body. The Cetacean probably flounder still more helplessly upon the ground.

In Birds, the attitude upon, and mode of progression over, soli

surfaces, is biped, or, as in the case of many birds, whilst resting or actually sleeping, the standing position is accomplished upon one leg only, or is uniped. The centre of gravity being situated very far forward in the body of a bird, owing to the great size of its pectoral muscles and wing bones, the trunk is usually held, in the standing position, inclined very little from the vertical direction, so as to bring the weight more over the base of support in the soles of the feet. The lumbar and dorsal regions of the vertebral column are very strong, and exhibit but little power of bending. To aid in supporting the weight, this base is extended forwards by the elongation of the phalanges of the toes; and to give the necessary rigidity to the trunk, the pelvis and lumbar region are solidified together, whilst the dorsal vertebræ are capable only of comparatively slight motion, the respiratory movements being performed rather by the descent of the sternum, than by any expansion of the ribs; the neck also, which is usually long in birds, to suit the prehensile character of the bill, is capable of being folded back over the trunk, so as to bring its weight over the base of support; the wings, as usually folded in walking, also serve to transfer weight to the hinder part of the body. In standing on a level surface, the weight of the bird is transmitted through the elongated metatarsal bones, and is then distributed through the several toes, the length of which varies in different species, according to the hardness or softness of the ground on which, in accordance to its habits, it usually has to run. In other instances, the foot is better suited for grasping more or less prominent surfaces, or even the trunks and smaller boughs of trees, bushes, or other plants ; in which case, the toes are shorter and stronger. In some scansorial tribes or climbing-birds, one of the three toes, which, in other birds, are turned forwards, is, at the will of the bird, or else permanently, turned backwards, so that there are two toes in front and two behind, an arrangement which gives great holding power. Many birds habitually perch upon boughs or branches, and in them the foot possesses a very perfect prehensile power; and, by a peculiar arrangement of the tendon of the flexors of the toes, when the weight of the animal bends the tarsus upon the leg, the tendon is stretched mechanically over the heel, and so serves, without further muscular effort, to tighten the whole of the toes upon the object which they grasp; moreover, on simply raising its weight, by extending the hinder limbs, the hold of the toes is simultaneously loosened, independently of any proper extending effort. In birds which sleep whilst perching, this mechanism is constantly employed, in certain instances, the animal sleeping securely by resting on, and grasping with, one leg only. The folding back of the head under the wing, an attitude so suggestive of repose, retirement, and reliant security, fulfils the further purpose of aiding in the easy preservation of the equilibrium of the body, by removing backwards the centre of gravity more completely over the now single base of support. There are certain birds of the crane-tribe, which have very long legs, and moderately prehensile toes, which still balance themselves in the daytime habitually on one leg, whether they sleep or not; in these cases, too, the head is drawn back under the wing, the centre of gravity is placed probably over, or nearly over, the column of support, and this is kept vertical by the extreme extension of the tarsal joint, and its stiffening by ligamentous connections.

A certain number of small birds seem to have no power of walking, but invariably hop over the ground, a movement which may be compared, in regard to its mechanism, with the leap in man; but most birds, whether large or small, can either hop or walk; the latter motion is much more frequently employed, and resembles the walking mode of progression in man, the action of the bird being truly biped, although the weight is supported on the phalanges and metatarsus, and not on the tarsal bones also. The running birds perform that movement on the two feet, alternately, as in man; and, in the case of the larger cursorial birds, as the ostrich, for example, the rate and endurance of the motion are very great; the speed of the ostrich is, indeed, said to be as high as that of the race-horse, and the great length and size of its lower extremities, and the diminution in the number of its toes, which, in some species, are only two in number, add, as similar arrangements do in the horse, to the solidity and security of the foot, as an organ of support and locomotion. The peculiarities of the lower limbs in climbing-birds, have already been noticed; in that action, the limbs are moved alternately, as in running.

In the four-footed Saurian Reptiles, the crocodiles, alligators, lizards, and others, the movement is essentially quadruped in its character and mechanism; but, with the exception of certain active lizards, and even they cannot long maintain their celerity, the motion of these animals is heavy and awkward; this is owing to the shortness of their limbs, the imperfect modelling of the articular surfaces of the bones, and the comparative want of energy in their muscular system; and something is also due to the length of their unwieldy body between the anterior and posterior limbs, and to the lateral position of the points of attachment of the limbs. In the apodous or footless reptiles, the Ophidia, or snakes, the body is no longer raised from the ground upon limbs, but its weight is supported on the under, or abdominal, surface of the trunk, and though the centre of gravity here occupies, as in all masses of matter, a single point, the weight is supported on an enormously long base, corresponding with almost the width and length of the animal, the head and adjoining part of the neck, however, being, as a rule, lifted from the ground. The manner in which serpents move over solid surfaces is threefold. First, they may fix the anterior part of the body, and drag the trunk after it, and then, again, project and fix the fore-part, following this by a second advancement of the hinder portion; this is called the geometric method of progression. Secondly, the animal holds upon the ground by successive portions of its abdominal surface, and throws the intermediate parts into slight vertical undulations. Lastly, and much more habitually, holding in the same way by its under surface, it throws the body into *lateral* undulations, and so advances over the ground. The mechanism concerned in these movements consists, first, of the extremely movable and flexuous vertebral column, in which the lateral play is commonly far greater than the vertical; secondly, of the intercostal muscles acting upon the ribs, which represent long levers attached to the sides of the vertebræ; and thirdly, of certain transverse cuticular plates, situated on the abdominal surface, attached at either end to the extremities of the corresponding pairs of ribs, covered with strong epidermis, and named the abdominal *scutæ*; these scutæ are imbricated, each overlapping the one behind it, so that their free edges are directed backwards; and, when elevated by proper muscles, they take a powerful

hold upon the ground, or upon other surfaces, such as projecting rocks, and the trunks and boughs of trees. Certain serpents coil themselves up into concentric rings, and then, resting the tail firmly upon the ground, holding by their scutæ, rapidly unfold their spires, and dart themselves for a certain distance through the air. The extraordinary locomotive powers of serpents, which can glide, or creep, or climb, or swim, or even spring through the air, are very remarkable, especially when their apparent locomotive inferiority, in the total absence of limbs, is considered. In the Chelonian Reptiles, or tortoises, the gait is slow and laboured, owing to their wide-spread, and laterally attached, limbs, the shortness of the levers of which these are composed, the comparative feebleness of their muscles, and the great proportionate weight they have to carry; the tortoise is proverbially slow. The turtles walk still more awkwardly, their extremities being adapted rather as paddles for swimming purposes.

Amongst the Amphibia, the motion is quadruped in the frogs, toads, and newts; but in the more defective species, as the proteus, the movement is rather of a creeping kind, the body being supported on its under surface. The energetic leap of the frog, is due to the great comparative length and strength of its hinder extremities; whilst the position of the animal, inclined at about an angle of 45° from the horizon, is that which is best adapted for obtaining the longest trajectory over the surface of the ground, with a given expenditure of power. The toads, which hop much more feebly, and often walk or run, have the body placed more horizontally, and the hinder limbs shorter than in the frog.

Amongst Fishes, the eel, in its migrations, sometimes crawls over soft mud-banks or grass, moving by lateral undulations, after the manner of a serpent, but much less easily, as it has no abdominal scutæ. There is a species of fish, the Anabas, of Tranquebar, which occasionally leaves the water for a time, and even ascends the trunks and branches of neighbouring low trees, accomplishing this by means of its pectoral and abdominal fins, which are, in fact, its anterior and posterior limbs. This animal is provided with a number of large cells on the side of its head, in which it can receive, and carry, a supply of water, for its gills, during its temporary aërial journey from its proper element.

Passing now from the Vertebrate to the Molluscous subdivision of the animal kingdom, we find comparatively few of this group which move over solid surfaces. The air-breathing terrestrial Pulmogasteropods (snails, &c.) creep over a solid surface by means of their muscular foot, which adheres closely, without the intervention of air, to the object to which it is attached, moving over it by means of longitudinal undulations, so minute and rapid, in some cases, as to require a magnifying glass for their detection; they may, however, be easily seen by watching, through a common lens, the under surface of a small slug or snail, creeping up a piece of glass. Certain Lamellibranchiata (the pectens) can project themselves from the bottom of the ocean, a short distance through the water, by means of a strong curved foot, which they thrust from their shell in a bent direction, and then suddenly straighten. Others have the power of turning themselves over, or dragging themselves along, step by step, by fixing and contracting a long muscular appendage.

The Molluscoida present no examples of motion on solids.

In the Annulose animals, locomotion over solids is a characteristic mode of progression, as in Insects, Spiders, Crustaceans, Myriapods, and Worms. In the higher forms, this is accomplished by means of limbs, many in number, provided with numerous joints, and acted upon, after the manner of levers, by powerful muscles. These muscles, however, as seen in the familiar example of the crab, are contained within the moving levers, instead of the levers being situated, as in the Vertebrata, amongst the muscles, and covered by them. These internal muscles of the Annulosa, are really a highly developed system of subcutaneous muscles, connected with the calcareous, horny or chitinous, coriaceous, or soft, integument, as the case may be; they are homologous with the panniculus carnosus, or hypodermal muscles, of the Vertebrata, and have no relation to the skeletal muscles of the last-named animals. The order in which the limbs of the higher Annulosa move, is absolutely definite for each class of these animals, and differs, according to the number of the limbs; thus, the Insects, having six legs, move after one mode; the Spiders, having eight legs, follow another; the Crustaceans, some of which have ten legs, have another; and the Myriapods, or many-footed creatures, a fourth mode. Without diagrams, these could hardly be made intelligible. In the Annelids, or Worms, the movement over solid bodies is accomplished, either by fixing the anterior extremity with the mouth, and drawing up the hinder one, and so on continuously, as in the leech; or a holding power is obtained by minute setæ, or bristles, set outwards and backwards, as in certain worms. In these cases, the extension of the body in a longitudinal direction, is accomplished by the contraction of numerous circular muscular fibres, which surround the body; whilst its required contraction in length, is brought about by the relaxation of these circular fibres, and the shortening of other longitudinal bands. Caterpillars move on a similar principle, but are provided with broad suctorial or clasping posterior feet, as well as with the characteristic three smaller, pointed and prehensile, anterior pairs. The numerous special contrivances exhibited in the extremities of the feet of the perfect insects and spiders, would require volumes to describe; sometimes they present hooklets (beetles), sometimes suctorial apparatuses (flies), and sometimes special adaptations, as in the spider, for holding upon webs. A great variety of special modes of locomotion may also be here alluded to, as the jumping of certain spiders, the astonishing leap of the flea, and the peculiar sideward mode of progression of certain spiders, and of the crabs; but for illustrations of these, and similar cases, reference must be made to works on Natural History.

Amongst the Annuloida, the Scolecida present a number of creeping animals. In the Echinodermata, which are entirely marine, there is in many species, as in the Sea-eggs, or Echini, a remarkable power of locomotion over the bottom of the sea, accomplished sometimes by so-called spinigrade progression, that is, by the motion of long spines, articulated with their shell, and moved by little muscles; in other cases, as seen in Star-fishes, a cirrhigrade progression is performed by the protrusion and working of numerous suctorial tubular cirrhi or feet, which are projected by being filled with fluid, forced into them by special muscular sacs lodged in the interior of the animal; by means of these the star-fish will even creep up the glass side of an aquarium. In the

soft Echinodermata, the Holothurida, the progression is of a mixed character, being cirrhi-vermigrade.

The Cœlenterata have no power of locomotion over solids, being entirely swimming animals; but amongst the Protozoa, the suctorial mode of progression over solids is exemplified in the Rhizopods, as in the simple proteiform Amœba.

Locomotion of Man in Fluids.

Owing to the lighter specific gravity of the human body, when the lungs are expanded, as compared with water, man is able to swim in that element, whether salt or fresh, with a small part of his frame above the surface. When the lungs are fully inflated, the body is lighter than water; after a complete expiration, it is heavier; but in an ordinary expiration it is about the same weight, bulk for bulk: hence, when the chest is fully inflated, a man may float with a small part of his body above water; but by a slight muscular effort, the head may be so thrown back, that, in this state, the mouth, nose, and eyes remain above the surface, but any unusual expiratory act is followed by the submergence of those parts. The smallest exertion of the feet in a treading motion, suffices however, even under these circumstances, to keep the face above the surface; and, if aided by the hands, this is still more easily accomplished. The buoyancy of the body is however so slight, in other words, its specific gravity is so little lighter than that of water, that, to maintain the face above the surface, every other part must be submerged; for if, whilst thus supported, one arm be extended out of the water, the head immediately sinks in a corresponding degree.

In the act of *swimming*, the body lies, with the abdomen downwards, in, but near the surface of, the water, and not quite horizontally, the head being inclined somewhat upwards, and thrown back, so as to sink as much of the hinder part of the cranium as possible, and to throw the face alone, with the breathing apertures, the nostrils and mouth, upwards and forwards out of the water. A progressive motion is then accomplished, by placing the hands together in front of the sternum, directing them forwards in the middle line, and then sweeping them outwards, with the fingers in contact, and the palms everted and turned slightly downwards, through a part of a circle, and lastly, bringing them quickly inwards to the front of the sternum again. In the meantime, whilst the arms are being extended forwards, the legs are drawn under the body, close

together, with the feet extended, and then, are thrust powerfully backwards and outwards, with the feet flat, at the same moment that the arms describe the part of a circle backwards. The combined propulsive action of the anterior and posterior limbs, moves the body forwards, and slightly elevates the head at each stroke; at this moment, inspiration and expiration should be accomplished. Swimming may also be performed on the back, with all four limbs, or on the side, using only one arm, but both hinder limbs. These modes of swimming are less rapid, but quieter, easier, and less exhaustive, than the ordinary mode on the face. The rate of motion of a swift swimmer is surprising, especially when it is considered that the rounded form of the human body is not well adapted for cleaving the water.

Locomotion of Animals in Fluids.

In *swimming*, land quadrupeds generally have this advantage over man, that, owing to the length of their neck, they can more easily maintain the orifices of the respiratory passages above the water. They also swim by an action of all four limbs, precisely similar to that which they habitually employ in locomotion on land, so that no training, as it were, is necessary for them in the art of swimming, but they swim quite naturally on first entering the water; whereas in man, the movements performed in that act, are so special and so different from the ordinary movements of locomotion, that he requires instruction and practic to accomplish them successfully; hence a land quadruped, when throw for the first time into water, swims with tolerable ease and certainty whereas a human being, if uninstructed, even if he succeeds in floating cannot accomplish any definite progressive motion through that fluid.

Certain quadrupeds fitted for an amphibious mode of existence, suc as the otter, beaver, seal, and water-rat, have their limbs speciall adapted for that purpose. In the two last-named animals, the feet a small, and the toes partially webbed; in the otter, the toes are distinctl webbed; in the seal, the anterior limbs are altogether paddle-like, the i teguments extending quite up to the last phalanges; the hinder-liml are placed almost in a line with the body, and are used somewhat lil the tail of a fish.

In the Cetacea, which, though breathing by lungs, are adapted e tirely to living in the sea, or the mouths of rivers, the swimming acti is, in a few cases, aided by short, paddle-like, anterior limbs (dugon but it is, in all, mainly effected by powerful alternate movements of t trunk and tail, which strike the water upwards and downwards like t body of the flat fishes, and not laterally like an ordinary fish. T caudal fin-like expansion of the cetacean has accordingly its surfaces rected upwards and downwards, instead of laterally, like the fish.

The specific gravity of birds, with their feathers perfect, is, as a rule, l than that of water. This is owing to the large proportionate siz their respiratory organs, the lightness of their bones, the cavities

hich are very large, though filled with fat instead of air in most wimming birds, and lastly, to the quantity of air which is entangled in ıeir down and feathers, and held there, because the oily secretion with hich they cover themselves, prevents its displacement by the water. Hence birds of this kind are so buoyant on the water that a much smaller roportion of their body is submerged than in the case of quadrupeds or f man. The form of the body, too, is suitable for floating, being boatke, and so curved at the fore part, and gradually narrowed behind, as to resent but slight resistance to the water, and the smallest amount of iction in the displacement of that fluid behind. The legs of swimming irds, are placed further back, and wider apart, than in land birds, and re articulated in such a direction, as to spread away from the body, rangements calculated to give lateral play to the actions of the feet, id to increase the efficacy of their propelling power over the body; oreover, the tarsi are flattened sideways, so as to present the smallest ossible resistance in being moved forward through the water; whilst the ıalanges of the toes, also long, compressed, and, when flexed, folded ery flatly together, spread out widely when extended, and are more less completely webbed, so as enormously to increase the power of ie stroke in the water in swimming. This stroke is backwards and a ttle outwards, so that both the limbs act on the water, along two lines verging outwards and backwards from the middle of the pelvis of the rd, the water reacts in the opposite direction, and the converging forces us obtained are combined, according to the rule of the composition of rces, into a resultant force, which impels the body directly forwards.

Swimming birds are ungainly in their walking gait, the backward osition of the legs necessitating a more horizontal position of the unk; the great width between the legs, the looseness of the joints, and e softness of the feet, give them a waddling and feeble motion in ılking. Diving birds have generally the centre of gravity of the body uated further back than other birds, the head, neck, and anterior rt of the trunk presenting a narrow or pointed form; besides the imtus with which they throw themselves into the water, these birds aid emselves by movements, not only of their feet, but also of their short d almost paddle-like wings.

A large number of the Saurian reptiles swim perfectly well in water, ıinly by lateral strokes of the hinder part of the body and tail, the tter being usually more or less flattened sideways for that purpose, and ing in the same manner as a fish's tail. In some cases, as in the ocodiles, the nostrils are placed at the tip of their long muzzle, so ıt they can completely submerge themselves, with the exception of e nostrils. The Ophidian reptiles can probably all of them swim, e water-snakes enjoying that faculty, however, in an eminent degree; this movement, the head of the snake is raised above the surface of e water for respiratory purposes, whilst rapid lateral undulations of e body are effected, by means of which the water is struck obliquely ckwards by a series of flexures, at intervals, on one side, and by other series of flexures on the other side; and the resultant action is presented by two oblique lines diverging, outwards and backwards, om the middle part of the elongated body; but the forward lines of retion of the water on each side, converge, and meet in the body, so that e resultant force of all the lines of reaction on the two sides, impels the

animal in an intermediate direction, that is, directly forwards. The Chelonian swimming reptiles (turtles) move in the water by means of both pairs of limbs, which have a paddle-like shape, and a lateral, wide-spread action, rotating on their axes, so as to be feathered, or to present their edge, in being drawn forwards, while they offer their flat surface to the water in the backward stroke. The compressed shape of the body of the swimming chelonia, offering so thin a transverse section in passing through the water, contrasts remarkably with the dome-shaped shell of the terrestrial chelonia or tortoises.

The tailed Amphibia (newts) swim, after the manner of the saurians, or ophidia, by simple, lateral, undulatory, strokes of the body or tail. The tailless Amphibia (frogs) swim by the force of their powerful hind-legs, provided with long and webbed toes. The stroke of the frog in swimming, is very similar to that of man, and it has often been noted that, in proportion to the size of the body, the frog has a larger muscle of the calf (gastrocnemius), for the extension of its foot upon the leg, than any other animal.

In the previous examples of swimming animals, we have had under observation creatures which, breathing by lungs, and requiring therefore, from time to time, and often at frequent and short intervals, to respire air, cannot be said to inhabit the water, but rather enter it for temporary purposes, for capturing food, or for other ends. They cannot endure continued submergence, except in conditions of hybernation. But we now pass to the contemplation of animals organised for permanent subsistence in, and complete submergence beneath, the water, breathing by gills. Fishes, considered in reference to their manner of swimming, exhibit three principal modes. First, the ordinary mode, by lateral strokes of the body, tail, and caudal fin, in opposite directions, as in common fishes; secondly, by the vertical flapping of the body, latera fins, and tail, or by vertical undulations of large lateral fins, or of a thin marginal fin, as in the flat fish, torpedo, turbot, sole, plaice, and flounder; and thirdly, by lateral undulatory movements of the body and tail, as in lampreys and eels. Besides this, there are exceptional mode of progression which we cannot notice here.

The first form of progression in Fishes, is the typical one. In th most perfect cases, the body of the fish is elongated, and its centre c gravity, and greatest transverse sectional area of displacement, are situ ated well forward, the form being suddenly narrowed to the nose, whils it is gradually narrowed backwards to the tail, a shape which, as has bee demonstrated by laborious calculations made in reference to shipbuild ing, offers the least possible resistance to progression through wate The body of the fish is deeper vertically than it is thick from side t side, a form which gives it stability in the water, by preventing rollin and affords more ample space for the attachment of the lateral plan of muscle, destined to deliver the powerful side strokes of the body ar tail. There are no vertebræ which can be called cervical, lumbar, sacral, but all are either dorsal or caudal. There is therefore n neck in the fish, so that the head is fixed directly and stiffly on th trunk, without the intervention of any weak portion or neck. T fins are of two kinds, viz. single and median, and double and lateral symmetrical, fins. The single fins are dorsal, caudal, and post-abd minal or anal; the first and last increase the lateral area of the fis

and add to its balancing power, whilst the caudal fin acts as an extension backwards of the tail, and so increases the power of its stroke. The lateral, double, and symmetrical fins are the right and left *pectoral*, and the right and left *abdominal* or ventral; these are the true *anterior* and *posterior limbs* of the fish; the pectoral pair are always situated at the under and back part of the head, just behind the gill-openings; the abdominal vary in their point of attachment in different species, from a place near or even anterior to the pectorals, backwards to the hinder part of the abdomen. These lateral fins are more used in the slighter balancing, ascending, descending, or turning movements of the fish, than as instruments of progression, that is, in ordinary fishes; for in the ray-tribe they are enormously developed, and form the chief organs of locomotion, whilst by the flying fishes they are employed in flight.

In the ordinary swimming movement, the tail, being first curved slightly forwards to one side, is then suddenly and powerfully extended backwards into the straight position, during which movement it strikes the water obliquely; next passing beyond the middle line, and curving slightly to the opposite side, it again repeats a sharp backward stroke, striking the water obliquely, across the direction of the former stroke, and once more passing the middle line, it repeats the former stroke, and so on in succession, on one side and the other. The reaction of the water takes place, of course, obliquely forwards, in the opposite direction to each backward stroke of the tail, and so tends to urge the centre of gravity of the fish in oblique zigzag lines forward through the water; but in rapid swimming, these two oblique forces are combined into a median resultant force, which impels the fish directly and swiftly forwards. Even then, however, a slight vibrating motion of the head is sometimes visible, the evidence of the double origin of its forward impulse. The question has often been asked, why is it that the resistance of the water to the forward curving of the tail, previous to its making the backward stroke, and in passing beyond the middle line after one backward stroke, previous to its performing another, does not check the movement of the fish forward, by counterbalancing the impulse arising from the backward movements of the tail? The reply to this question appears to be twofold; first, the backward stroke is delivered not only with greater force, but with greater velocity than the forward curving of the tail; and as time is always an element in measuring the effects of force, the backward stroke is superior in practical effect; secondly, the resistance to the forward movement of the fish in the water, is reduced, as we have seen, to the smallest possible amount, first, by the form of the body, and, secondly, by its slipperiness, which prevents friction, whereas to any backward movement of the fish in the water, the edges of the scales, elevated slightly from each other by the curving forwards of the tail, take powerful hold of the surrounding fluid, and so offer great resistance to any sliding backwards of the fish. Whoever has hooked a fish accidentally by the tail, knows how much more difficult it is to lift or drag it through the water, than if it had been caught by its seizing the bait in the ordinary way; a fact which proves the resistance offered by the edges of the scales.

In describing the act of swimming in the fish, we must not omit to mention the existence, in most species, of the air-bladder, or swimming-bladder. This is an elongated receptacle, containing gases secreted by

its lining membrane; it varies in form and size, and is situated in the upper part of the abdominal cavity, immediately under the vertebral column; sometimes it is completely closed, but at other times it communicates by a narrow, elongated neck, with the throat, pharynx, or some part of the alimentary canal, of the fish. The air-bladders of fishes will be referred to again in the chapter on Respiration; but, in connection with our present subject, it is obvious that its presence, or absence, and its relative state of distension with gaseous matter, must materially affect the specific gravity or buoyancy of a fish. It is supposed that the fish has some power of regulating the quantity of gas contained within it, and so of adjusting its own specific gravity, to enable it to rise or fall in the water; but no such faculty has been actually proved to exist, and it seems somewhat improbable that the vito-chemical function of such an organ, which is the homologue of the lung, should be subjected directly to the will. It is noticeable also, that the air-bladder appears to be very capriciously distributed amongst the fish-tribe, for it is wanting, not only in certain genera amongst certain orders, but also in certain species of a genus, other species of which possess it. Thus there is no air-bladder in the common mackerel, though one species of the same genus (Scomber) possesses it. It is, however, small in fishes which bury themselves in the mud, or live habitually at the bottom of the water; in the common perch, it is closed. Even when fully distended with air, almost to bursting, as I have demonstrated on various dead fish, it fails to render the entire body buoyant in water, for this nevertheless sinks to the bottom. Mechanically considered, it can therefore only reduce the specific gravity in a certain measure, and so economise the muscular effort which is still necessary to enable the fish to ascend in that fluid; whilst the absorption of its gaseous contents will, on the contrary, increase the rapidity of the descent of the fish by its gravity merely. A possible explanation of its use may be, that it serves to render the ordinary attitude of a fish, with its back upwards in the water, more easy to be maintained; for without it, the specific gravity of the upper or dorsal half of a fish is greater than that of the under or abdominal half, owing to the presence of the vertebral column in the former, a difference which would be easily diminished by a minute horizontal column of air placed in the upper half. The adaptability of different fishes for the act of swimming, differs exceedingly according to their form; the swiftest swimmers are those in which the form is rather elongated (herring, salmon, shark); the heterocercal fishes, which have the vertebral column prolonged to the extremity of the upper caudal fin (sharks), are swifter swimmers than the ordinary or homocercal fishes, in which the cleft caudal fin extends beyond the vertebral column. Many fishes swim very rapidly; the salmon is said to travel from twenty to twenty-five miles in an hour. Certain globular forms of fish (diodon, sun-fish) either move sideways slowly, or turn over and over in the water.

Fishes which swim in the third general mode mentioned above, viz. by lateral undulations, effect this object on the same principles as have been already explained in regard to the water-snakes; but they swim submerged instead of on the surface, and invariably have the advantage of the extension of their lateral area by a continuous marginal dorsal and ventral fin. In the flat fishes (sole, turbot), the flapping of the body

and the undulatory or wriggling movement of the marginal fins, produce their effect by striking the water obliquely backwards, but in an upward and downward, instead of a horizontal direction; the reaction of the water upon them, takes place therefore along two converging lines, from above and below, instead of from the sides. In the true flat-fish which have no air-bladder (sole, turbot), the flat form of the body is owing to an extension of the neural and hæmal spines, the fish swimming with one side, which is generally white, downwards, and the other, which is brown, upwards. In the skates, rays, and torpedoes, the flat form is owing to the extraordinary development of the anterior or pectoral fins; these spread out horizontally, and are provided with innumerable digits which support the soft parts, and thus form large lateral fins, which, in addition to the tail, are used in swimming.

In the Molluscous animals inhabiting the water, swimming is performed either by the movement of their long arms acting as paddles (cephalopods), or by special little lateral wing-like paddles (pteropods), or by fin-like expansions of the foot, and vertically flattened tail (heteropods), or by aid of the movable respiratory organs or gills (certain marine gasteropods). Of the lamellibranchiate forms, some are fixed, like the oyster, others are attached by a byssus, as the mussel and pinna; some float in the water, and others, like the cockle, jump through the water from the bottom, by aid of their long curved fleshy foot; some bury themselves in sand, whilst others bore into rocks or timber. The free moving Molluscoids mostly float, as the tunicata.

In the Annulose creatures, many, such as the Crustaceans, move by means of the paddle-like action of their numerous limbs, some of these (lobsters and shrimps) also jumping or propelling themselves backwards in the water by rapid flexure of the tail, which for that purpose is fitted with expanded terminal appendages; others of this sub-kingdom, as the water-beetles, use their limbs as oars (notonecton); others move by the action of multitudes of lateral setæ attached to each successive segment (aphrodite, sea-mouse); others swim by undulatory movements of the body, either by lateral (vermes), or by vertical undulations (leech); others again, in the larval stage of their existence, propel themselves by ejecting water from a receptacle in their body, backwards from their caudal extremity, a movement characterised, from its resemblance to the action of a syringe, as *syringograde*. Of the swimming Annuloids, in certain echinodermata, the swimming motion is sometimes *pinnigrade*, or performed by movable pinnate arms, as in the crinoidea; the rotiferous animalcules move in the water by means of their cilia; the marine worm-like scolecida move by an undulatory action of their bodies.

In the free moving Cœlenterata, one form of movement in the water, often named *pulmograde*, is performed by rhythmical contractions, which occur once in about eighteen seconds, of the entire umbrella-like disc of the animal (Medusæ), and which might be compared to the pulsations of the heart, or to the respiratory movements; other species simply float in the water by means of hollow air-floats or vesicles (Physalia, Portuguese man-of-war), a method of progression called *physograde*; or they have a *syringograde* mode of progression; or, lastly, they move by means of rows of very large cilia, *ciliograde*, as in Beroe, Cydipus.

The ciliograde mode of progression is also invariably employed in the swimming acts of the Protozoa, as in the infusoria, and in the gemmæ of sponges.

Locomotion of Man in Air.

This is impossible, except as the result of impulses obtained from solid supports, combined with the effects of gravity. The extraordinary agile, graceful, easy and perfect acrobatic movements of the celebrated Leotard are thus performed, and surpass in elegance the similarly executed movements of the spider monkeys, and of other arboreal, and so-called flying mammalia.

Locomotion of Animals in the Air.

Flight, in its highest perfection, is a movement limited, amongst the Vertebrata to Birds, and in the Annulosa to Insects. Amongst the Mammalia, however, the comparatively feebly flying bats are found. Certain examples are also seen, as in the flying lemurs and squirrels, of a parachute-mode of descent in the air, which cannot be called flight, for such animals are unable to ascend, or even to move horizontally in that medium; the source of movement in them, is their gravity, the direction of the action of which is altered by the membranous expansions passing from one limb to the other, which are stretched by the spreading out of their fore and hind limbs. In the bats, there is a true power of flight, but it is imperfect in comparison with that of birds, being short in its duration, low in reference to the earth, irregular and fluttering in its character, and incapable of being performed in very gusty weather, or in rain, which drenches the hair and wings of the animal, and so impedes its movement: bats chiefly inhabit temperate climes, and limit their appearance on the wing, to serene evenings and nights. The sternum of the bat is proportionally large, and developed downwards into a slight keel for the attachment of a pectoral muscle, which is larger in comparison with the body, than in any other Mammalia; their clavicles and scapulæ are strong, to afford resistance to the drawing inwards of the shoulders in flight; the arm and fore-arm are elongated, and so especially are the metacarpal bones and phalanges of the three outer fingers, between which the web-like expansion of the wings is stretched. This web always extends the whole length of the trunk, backwards to the short hinder limb, excluding the foot; and sometimes it is continued on to an elongated coccyx or tail, which is used as an effective rudder. The foot, free from the web, is used for prehensile purposes, the bat hanging with its head downwards, and even sleeping, and in cold climates hybernating, in that position. In the fore-limb or hand, the thumb is also free, and hooked as a prehensile instrument. The pectoral and other muscles of the fore-limb, are very largely developed.

Passing over Birds to Reptiles, we have to select as examples of true, though probably of awkward flight, the extraordinary extinct flying reptiles (pterodactyles, &c.), the formation of the sternum and upper limbs of which, sufficiently indicates the manner in which they were used, but leads to the inference that their flight was probably merely an occasional mode of progression, sustainable for short intervals only. Amongst the living reptiles, the little so-called flying-lizard or dragon,

affords an example of the parachute mode of progression; its lateral membranous expansions are supported by bony processes belonging to the lumbar vertebræ, sometimes named false ribs, but placed altogether behind the proper thorax; these membranes are capable of being shut up, owing to the movableness of the bony processes which support them; and they are extended by special muscles which draw those processes forwards. In the flying Fishes, the so-called flight is accomplished by an impetus taken from the water, by the agency of the tail, and of the long powerful pectoral fins, which latter are then spread out in the air, so as to look like wings ; but they have only very feeble muscles at their base, and they merely perform a parachute action, and so sustain the animal for a distance of many feet in the air, before its gravity again accomplishes its descent into the water. Flying fish have been known to rise fifteen or twenty feet from the surface of the water, but the usual height is not more than three feet; they may remain suspended in the air about half a minute, and thus pass through a distance of even 300 feet.

In Insects, the mode of flight is explicable on similar principles to those which regulate it in Birds; but here, also, as was mentioned in comparing the locomotion on land, of the Annulosa with that of the Vertebrata, the muscular or moving apparatus is placed within the passive levers on which it acts, instead of outside them. The wings of insects are variously constructed, and present various sizes and forms ; they are horny and membranous, in the beetles ; soft, and feathered with microscopic scales, in the moths and butterflies ; thin and glassy-looking, in the flies and dragon-flies ; short, in the earwigs and house-flies ; long and narrow, in bees and wasps; broad and full, in butterflies ; and enormously elongated in the dragon-flies. Sometimes they are only two in number (diptera); sometimes the anterior ones are converted into protective cases or elytra (beetles); but more commonly they are four in number. These wings, however different in character, are invariably attached to the sides of the thoracic segments, above the proper limbs or legs ; they are moved by powerful muscles lying inside the thorax, that part of the body of an insect being developed proportionally to its powers of flight. The base of the stiff framework of each wing, projects into the interior of the thorax by a sort of process or spur ; and the muscles act upon this spur, those which draw it downwards raising the wing, and the far more powerful ones, which draw the spur upwards, acting in the downward stroke ; so that the muscular force is applied in the opposite direction to that in which it acts in the bird or bat. The rapidity, duration, and character of the movement performed by different insects on the wing, depend on the area of their wings, on the number of strokes made in a second, and on the character of those strokes, whether rapid and continuous, as in the dragon-fly, or slower, and more interrupted and fluttering, as in the butterfly. Insects, considering their size, fly with much greater rapidity than birds ; the dragon-fly, for example, flies more rapidly than the swallow ; this insect has also much greater control over its organs of flight, and can execute a greater variety of movements in the air, even than the most agile bird.

In the Amphibia, amongst the Vertebrata, and in the Mollusca, Molluscoida, Annuloida, Cœlenterata, and Protozoa, there are no examples of flying species.

The organisation of birds is entirely, and in every part, directly

adapted to flight. First, their biped position in standing and walking, leaves the upper limbs entirely free for locomotion in the air. In the standing posture, the body of the bird is generally raised forward to bring the centre of gravity over the feet, excepting in many swimming birds, as the duck, and others. In flight, the body is usually held more horizontally, and the centre of gravity lies very far forward, a position favourable to that mode of locomotion. In walking, the axis of motion is placed far back, at the hip-joints, but in flight, forward, through the shoulders; and this change in the seat of motion, requires different compensatory changes in the position of the body. The length and free motion of the neck, also render the adjustability of the centre of gravity in flight much more easy. The concentration of weight forward in the trunk is accomplished by the muscular masses being chiefly situated there; the limbs contain the tendons only. The absolute weight of the animal is also diminished as much as possible, in regard to its size and strength, by various conditions, such as the extreme lightness of construction of its skeleton and feathers, the expansion of their solid matter, and the presence of air in the bones and quills. The large size of the lungs in birds, the presence of air cavities in the body, and even in the bones, the rapidity and energy of their respiratory movements, their consequent high temperature, and the rarefaction of the contained air, are associated circumstances which have been supposed to result in an important diminution of the specific gravity of the animal; but the difference in weight between air at the ordinary temperature, and at 180°, that of the hottest bird, is insignificant, in proportion to the weight of the entire mass of the bird. The chief relation between the energetic respiration of birds, and their adaptation to flight, consists in the provision, through the former, for the rapid decomposition and oxidation of the large muscles engaged in that movement; and also in its endowing the muscular fibre with an unwonted degree of contractility. It is supposed, that the air cavities which occupy spaces between the abdominal viscera, may assist respiration during flight, when the sternum and ribs require to be comparatively fixed, and cannot be used in the respiratory movements, which must then be performed chiefly by the action of the abdominal muscles.

The dorsal and lumbar regions of the spine, in birds, are strong, and comparatively immovable, so that the trunk forms a firm basis for the support of the vibration of the wings; the consolidation of the trunk being, as a rule, proportioned to the powers of flight. The head is usually tapering, so as to offer slight resistance to the air; the neck is long, and can be extended or drawn back, so as, amongst other purposes, to shift the position of the centre of gravity in flight. Moreover, the length of the neck, and the conformation of the jaws, convert the head into a prehensile organ; and as the feet are organised for standing, walking, perching, climbing, or swimming, or for prehensile purposes, the wings are left free to be specially organised for aerial locomotion. Turning to the special contrivances in these parts, we find, first, a double bony arch between the shoulders,—the one, posterior, formed by the coracoid bones, resting on the sternum, and articulating with the scapula; and the other, anterior, formed by the merry-thought, or furcular bone, consisting of the two clavicles united together in front. This compound arch gives stability to the shoulder-joint, by resisting inward

thrust. Secondly, must be noticed, the vast surfaces of the sternum, which reaches backwards, sometimes as far as to the pubes, with its deep projecting keel for the attachment of the large, and the two smaller, pectoral muscles, which, often weighing as much as all the other muscles of the body, serve powerfully to depress, and more gently to elevate, and slightly rotate the wings. Other remarkable points of structure are the length of the humerus, radius, and ulna, the simplicity and solidity of the tarsus, and the degradation of the phalanges to a few flat supporting bones for the attachment of feathers. As regards the joints, their movements are specially limited, those of the elbow and tarsus performing simple hinge-like movements; the latter joint being limited to adduction and abduction, so as to have special firmness when extended; and the shoulder-joint moving merely in the directions of extension and flexion, and in the upward and downward direction. The wings present many points of special contrivance; as, for example, the strong attachment of the stiff quill-feathers to the periosteum of the bones of the fore-arm and hand; the curved form, from quill to tip, of these feathers; their peculiar structure, the partial hollowness of their stems, their stiff, horny exterior, and the light pithy character of their contents; the close parallel arrangement and vertical depth of the barbs; the shortness and stiffness of the anterior barbs, as compared with the greater length of the posterior barbs; the secondary barbs, or barbules; the interlocking of the barbules of each feather; the overlapping of the several quill-feathers, the position of which is regulated by multitudes of small muscular slips lying in the skin, there being sometimes four or five slips to each quill-feather; and, lastly, the stiffness of the anterior margin of the wing, as compared with its hinder edge, and the marked concavity of the under surface of the wing, as contrasted with the convexity of its upper surface.

The rarity of the medium in which flight takes place, the slight mechanical resistance it offers, and its feeble sustaining power, dependent on the extreme difference between its specific gravity and that of the bird, necessitate special contrivances, and an enormous relative amount of effort on the part of a flying animal, to sustain or support its weight in the air; but, on the other hand, the resistance to motion through such a medium is so slight, that comparatively little forward impulse is sufficient to propel it through the air. In accordance with these necessities, the wings of the bird operate on the air chiefly in a *vertical* direction; but, be it observed, owing to the more yielding nature of the hinder edge of the wing, the air escapes under that edge, which is lifted up, so that the efficient action of the stroke is not directly downwards, but downwards and a little backwards in the air. The reaction of that medium takes place against the wings in the opposite direction, that is, chiefly upwards, but slightly forwards; and the combined result is to sustain, or lift, the centre of gravity of the body of the bird above the tips of the descending wings, and to urge it also forwards. The former act demands a very large expenditure, but the latter a comparatively small outlay of wing force. The wings, having made their downward stroke, are lifted, and then again descend, and so on. The reasons why the descending stroke of the wing is more effective than the upward movement, are these: first, the holding power of the wing is increased by the concavity of its under surface, and by the concavity

of every quill-feather, also by the overlapping of these, and the locking together of their barbs and barbules; whilst in the upward movement, the air passes off the convex surface of the wing and its chief component feathers, and, as it were, filters through, behind the weaker posterior barbs of each feather, and through their unlocked barbules. Secondly, it is probable, that the area of the wing, owing to its more perfect extension, is slightly greater in its downward movement, than during its upward movement; a condition also favoured by the further yielding and bending of the quills and wings in the upward movement, as compared with their stiffness and diminished curvature in the downward stroke. Lastly, force and time being joint elements in the development of a given momentum, it is probable that the downward stroke is accomplished with greater energy and velocity than the upward movement. Be this as it may, without an extraordinary difference between the efficient action of the downward and the upward movement of the wing, no sustaining, much less a lifting, power would be gained, and the force of gravity would cause the bird to descend to the ground. By rapid strokes of the wings, slightly rotated and firmly held, in a directly downward direction, the bird is lifted upwards perpendicularly in the air. In hovering over one spot, the wings appear to act directly downwards, but probably they are so rotated forwards, as to counteract the effect of the sliding of the air from behind their posterior edges; and thus they merely support the bird at one spot in the air. Progressive movement requires in addition, a slightly oblique force exercised, as just described, downwards and a little backwards, so as to produce a reactionary force of the air upwards and a little forwards. The effect of gravity alone, when once the bird is raised sufficiently high in the air, will produce, owing to the easier escape of the air behind the weak edge of the wings, a forward but gradually descending movement, which is known as sailing through the air. In gliding or skimming obliquely downwards through the air, some birds use their wings outstretched, after the manner of a parachute, whilst others alternate the flying and the parachute movement; some fly continuously, others by jerks, rising by rapid movements of the wings, and falling when these are quiet. The tail operates, in regulating or checking the descent of the bird, obliquely, by gravity. It is also employed as a rudder by which to steer the bird, or to cause it, during active flight, to ascend or descend in the air; when the tail is bent downward, the resistance of the air beneath and in front of it, causes the head of the bird to ascend; when it is raised, on the same principle, the bird is made to descend. The direction of the flight, to one side or the other, is said by some to be caused by the more rapid vibration, and perhaps by the changed position, of the opposite wing, rather than, as supposed by others, by any lateral action of the tail. Some birds, especially sea birds, have a remarkable power of flying, or gliding, on their sides in the air, or of turning completely over; tumbler-pigeons make summersaults over and over again. The protrusion, or retraction, the elevation, or depression, or the lateral movement of the head and neck, which will shift the centre of gravity in corresponding directions, must also aid in determining the direction of flight.

The flight of some birds is very rapid, reaching, it is said, to ninety miles an hour, in the Eider duck, and even to one hundred and one hun-

dred and fifty miles an hour, in the case of certain hawks and falcons. The wings, the characteristic locomotive organs of birds, are sometimes, as in the penguins and auks, modified by being shortened and provided only with short, stiff, closed feathers, so as to act like fins, or paddles, especially in the movements of diving and swimming beneath the surface. In the cursorial or running birds, such as the cassowary, ostrich, and apteryx, the sternum is short, and its keel absent; the clavicles are small, attached firmly to the scapulæ by bone, but do not reach each other in front; the clavicles are even sometimes absent; in these birds, the wing is small, or so rudimentary as to be wholly unlike a wing.

Prehension and Manipulation in Man.

By far the most complicated prehensile instrument in animal mechanics, is the human upper limb; and the singular perfection of all its parts, and especially of its terminal segment, the hand, makes it the most perfect manipulative organ with which we are acquainted, and well fitted for the execution of the various designs and behests of human ingenuity and will. The negative qualities of the human upper limb, considered as a locomotive organ, constitute positive adaptations for its prehensile and manipulative purposes. Amongst these, may be mentioned the following:—its smaller size, as compared with the lower limb; the sole bony attachment between the inner end of the clavicle, and the sternum, so slight in comparison with the solid connection of the pelvic bones with each other, and with the vertebral column; the consequent extreme mobility of the scapula and clavicle upon the trunk, as contrasted with the immovability of the pelvis; the shallow socket of the shoulder-joint, and the almost unlimited character of free play of its movements, as contrasted with the deep hip-joint, and its more restrained motions; the complex nature of the elbow-joint, and especially the separate movements of the radius upon the ulna, for the pronation and supination of the hand, as contrasted with the fixity of the tibia and fibula; the lightness of the carpal bones, fig. 53, 1 to 8, as contrasted with the large size of those of the tarsus (compare figs. 51 and 53); the articulation of the hand in a line with the fore-arm, instead of at right angles, like that of the foot upon the leg; the greater length of the metacarpus, fig. 53, 9, in relation to the carpus, as contrasted with the more equal length of the tarsus and metatarsus, fig. 51; the standing out of the first metacarpal bone from the rest, fig. 53, so as to support the opposable thumb; the great relative length of the phalanges of the fingers, 10, 11, 12,—those of the middle finger being

about equal in length to the carpus and metacarpus together, whilst, in the foot, the phalanges are not longer than the metatarsus only;—and lastly, the super-addition of particular muscles, not represented in the lower limb, as for example the pronators and supinators of the fore-arm, and certain special muscles, viz. the long extensors, and the opponens, belonging to the thumb, and the proper long extensors of the fore and little fingers. The great toe, however, is also well supplied with muscles, and possesses, in certain races, a slight prehensile power.

Fig. 53.

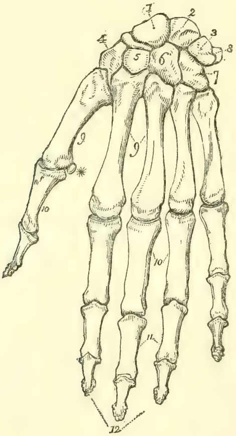


Fig. 53. Dorsal or back view of the bones of the left hand, showing the smallness of the carpus, the lightness and length of the phalanges, the distinct position and length of the thumb. 1 to 8, carpal bones, viz:—1, scaphoid; 2, semilunar; 3, cuneiform; 4, trapezium; 5, trapezoid; 6, os magnum; 7, unciform; 8, pisiform; 9, 9, the five metacarpal bones, that of the thumb standing out from the rest; 10, 10, first phalanges; 11, second ditto; 12, last or ungual phalanges; * sesamoid bones of thumb.

The following details in the structure of the upper limb, require also to be mentioned. The shallow socket on the outer angle of the scapula, called the glenoid fossa, looks neither directly forwards nor outwards, but outwards and forwards. In this socket, the articular surface of the head of

the humerus, which forms only $\frac{1}{3}$ of a spheroid, instead of $\frac{2}{3}$, as in the case of the femur, moves freely in all directions on the scapula; but the joint is protected by the tendons of many muscles, and is, moreover, overhung by one process of the

Fig. 54.

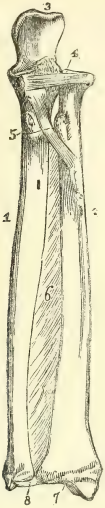


Fig. 54. The radius and ulna of the left fore-arm, seen in front, tied together by their ligaments, to show the mechanism of the joints concerned in pronation and supination. 1, the ulna; 2, the radius; 3, the olecranon process, below which is the great sigmoid notch for the reception of the trochlear surface on the lower end of the humerus; 4, the orbicular ligament, which springs from the ulna, and embraces the head of the radius, without being attached to that bone; 5, the oblique or check ligament; 6, the interosseous membrane; 7, the broad lower end of the radius, with which the hand is chiefly connected; 8, the interarticular fibro-cartilage which passes from the edge of the lower end of the radius, to the styloid process at the lower end of the ulna, without being attached to the lower articular end of the latter bone.

scapula, above, named the acromion process, and by another, the coracoid process, in front. The elbow-joint (page 192) presents, on its inner side, a trochlear or pulley-like surface, on the lower end of the humerus, which is received into a deep

notch (the greater sigmoid), fig. 54, found on the front of the olecranon process, 3, at the upper end of the ulna; the two bones are thus so securely fitted, that the ulna moves upon the humerus, in the direction of flexion and extension only. At the outer side of the elbow-joint, the lower end of the humerus is provided with a rounded eminence, continuous with the trochlear surface just mentioned, and having the upper end of the radius, 2, which is slightly hollowed, fitted to it. The inner side of the head of the radius, also smooth and articular, and therefore covered with cartilage, is received into a small notch (smaller sigmoid) on the outer side of the ulna, and a strong collar-like ligament, named orbicular, 4, passes from both borders of this sigmoid notch, and embraces the head of the radius, without being fixed to it. Hence, although, at the elbow-joint, the radius is carried to and fro with the ulna, upon the humerus, in the movements of flexion and extension of the fore-arm upon the arm, yet, provision is made in the mode of articulation of the radius and ulna at their upper ends, for that peculiar motion between the two bones, which constitutes pronation and supination of the fore-arm and hand.

A line drawn through the elbow-joint, from side to side, is oblique, the inner condyle of the humerus being longer than the outer one; in consequence of this, when the joint is flexed, the fore-arm is not bent directly upon the arm, but is carried to its inner side, that is, a little over the body; a similar inclination inwards of the hand, when it bends at the wrist carries it also still further in front of the body, and hence the hand is brought, by the mere mechanism of the articula surfaces, into a position of constant utility and advantage. A its lower end, the radius is widened out, fig. 54, 7, and roll upon the ulna, the two bones being tied together by a stron fibro-cartilage, 8, which passes from the inner border of th radius and neighbouring ligaments, below the articular end c the ulna, to be attached to the styloid process of that bone a small notch on the side of the radius, receives a rounde part of the ulna, the reverse arrangement to that which take place at the upper ends of the bones, where the radius received into the ulna. The hand is principally connecte with the lower end of the radius, the lower articular surfac of the ulna being excluded by the fibro-cartilage just mer tioned; hence, the hand moves with the radius, and whe that bone is rolled upon its axis, supported on the ulna, tl hand moves with it, the rolling motion inwards, in which tl

palm of the hand is turned downwards, being called *pronation*, from the word prone (lying on the face); whilst the rolling motion outwards in which the palm of the hand is turned upwards and its back downwards, is called *supination*, from supine (lying on the back).

This most admirable arrangement multiplies the use of the hand, enabling it, by this simple additional movement, to operate upwards or downwards, or at any intermediate point. The general motion at the wrist joint is of a hinge-like character, but slight lateral movements increase the flexibility of the joint in those directions, and this is also augmented, in the direction of flexion, by the arrangement of the carpal bones into two rows. The hand itself is slightly arched transversely in the palm, like the foot in the sole, but scarcely so from before backwards; the concavity of the palm is not intended to give it strength as an organ of support, but besides affording protection to important bloodvessels and nerves, it serves to adapt the hand for holding purposes; moreover, the ends of the metacarpal bones on which the fingers are supported, when looked at endways, are seen to form a curved line, in consequence of which the fingers, when closed, are thrown together, pointing towards the middle of the palm, and are more easily opposed to the thumb. The joints at the base of the fingers, being ball and socket joints, those digits may be spread out laterally, and each may be moved upon its base, in any given direction; whilst the succeeding two joints, being hinge joints, a certain definition and greater firmness are imparted to the movements of the phalanges themselves. Whilst each finger at its base, and at the last joint, can be bent ordinarily only to a right angle, the intervening or second phalangeal articulation can be bent to an acute angle, an arrangement favoured by the splitting of the extensor tendon over the back of that joint; this arrangement evidently permits of a more perfect grasp. The separation of the first metacarpal bone, which supports the thumb, from the rest, instead of being parallel as in the foot, and the opposability of that digit to the other fingers, have already been mentioned; the joint at the base of that metacarpal bone, next to the wrist, instead of being a gliding joint like the others, is a modified ball and socket joint, capable of movement in all directions; the two remaining joints of the thumb are, however, hinge-joints.

The great distinguishing characteristic of the human hand, as compared with the hand of the so-called Quadrumana, is,

besides the better proportion of the fingers, the relative length and perfection of its thumb, which, when the hand is extended, reaches a little beyond the middle of the first phalanx of the fore-finger ; whereas, in no anthropoid ape, does it even reach beyond the base of that finger. It was formerly supposed that the presence of two extensor tendons in the fore and little fingers, was a peculiarity especially human ; but a double extensor tendon is common in the fingers or toes of quadrupeds, even though only the middle digit remains developed.

It is necessary to add, that by the combination of length with strength, and by the more refined character of the tactile endowment of its broad pulps supported by its expanded nails, as well as by its general mechanism and movements, the human hand is likewise distinguished from the hands of the anthropoid apes and the monkeys.

Prehension and Manipulation in Animals.

As just implied, the hand, in the anthropoid apes, is characterised by the length of the fingers, and the shortness of the thumb. That of the gorilla, exceeds, in size and power, the human member ; the shortness of the free portion of the fingers, owing to the extension forwards upon them of the skin of the palm, together with the shortness of the thumb are characteristics which, though they may increase its mere grasping power, detract from it, in comparison with the human hand, as an instrument for varied work. The length of the entire limb, and that of the muscles also, are further sources of strength in these animals the latissimus dorsi muscle is attached to the olecranon process, or elbow which is never the case in man (fig. 5, 3). In the anthropoid apes, th chimpanzee, the ourang, and the gibbon, the fingers are proportionall longer, and the thumb shorter and weaker. In the still lower monkey the long and taper fingers, and the diminutive, and often not opposabl itarthumb, limit the use of the limb to a compavely feeble grasp, an constitute a practical mutilation of the member. In the spider mon keys, with their long grasping fingers, the thumb is wanting. In a cases, however, the general formation of the upper limb, in the apes ar monkeys, is similar to that in man ; but the length of its various se ments is such, that it is longer in proportion than the lower limb,— circumstance which fits it better for partially bearing the weight of tl animal in locomotion, but which renders it more awkward and ungain as a dexterous prehensile, or manipulating organ. It must not overlooked here, that, in all the apes and monkeys, the foot is also pı hensile, or hand-like, in its action, though it is a foot in structur hence the use of the term Quadrumanous is not anatomically, though is teleologically, correct. In the lemurs, the hand is distinctly lo motive, as well as simply prehensile ; the thumb is here wanting.

Next to the monkeys and lemurs, a prehensile power is manifested the limbs of the Carnivora, especially in the feline tribe, in which t hinder, as well as the fore-limbs, are both prehensile and locomoti

In the hinder limb, however, the phalanges of the first or inner toe are absent, and the first metatarsal bone is rudimentary. There is a special contrivance in all four limbs of the cat tribe, by which the last phalanx, which is curved, and provided with a bony sheath for the firm attachment of the hooked claw, can be withdrawn, or protruded, at the pleasure of the animal. At the inner side of the last phalanx but one, is a lateral process, or projection, upon which the last phalanx plays; certain elastic ligaments, passing from one to the other, keep the claw habitually retracted, without effort on the part of the animal, and thus out of the way, in ordinary locomotive acts; but the powerful flexor muscles of the last phalanges move the claws forwards, and so protrude them, when the feet are used for prehensile purposes, as in climbing, or in holding prey, or in acts of offence and defence. It is obvious that these retractile claws are, in this way, saved from unnecessary wear, and are not protruded to the inconvenience of the animal in simple locomotion. A certain power of pronation and supination of the fore paw, is permitted in these animals, by a moderate rolling movement of the radius on the ulna; but this is not to be compared with what is found in the apes and monkeys, in which it equals that possessed by man. In the bears, a greater amount of pronation is permitted than in the cats.

The prehensile power of the limbs, in animals lower than the carnivora, begins to disappear, first from the hinder limb, and then from the fore limb also; the squirrel and the kangaroo have already been mentioned, but with these, and a few other like exceptions, the fore limb comes to be used perhaps as a burrowing, or climbing, member, but more commonly as a locomotive organ of some kind or other; and the prehensile faculty of the animal is exercised either by the lips and jaws, or else, as in the case of the elephant's proboscis, which possesses not less than 40,000 separate interlacing muscular slips, by a special muscular organ provided for that purpose. The tail also, in certain Quadrumana, as in the spider-monkey, which has no thumb in the hand, is a prehensile organ of great length and power. In accordance with the adaptation of the fore limb to purposes of locomotion only, the movements of pronation and supination between the radius and ulna, are absent in the Ruminants, Solipeds, Cetaceans, and others. In the mole, the burrowing power of the fore limb is provided for, by the shortness and width of the humerus, radius, and ulna, by the limitation of the movements at the shoulder and elbow, and by the presence of a curious sickle-shaped bone, situated between the radius and the base of the thumb, which serves to increase the width of the strong hand. In this animal also, the clavicle is strong, is articulated in a peculiar manner, and has a very large subclavius muscle attached to it.

The characters and structure of the prehensile organs in Birds, viz. the bill and jaws, and the feet and claws, do not require special explanation; neither do those of the powerful prehensile jaws and teeth of the dolphins and porpoises, amongst the Cetaceous mammalia; nor of the large Saurian Reptiles; nor of the sharks, and other predaceous Fishes; nor yet the feebler instruments of the soft-skinned Amphibious Animals and the smaller Fishes. The tongue, in the parrots, is large, and acts against the upper jaw, in holding and turning the food; in the honey-feeding humming-birds, the tip of the tongue is

filamentous; in the woodpecker, its point is barbed. The tongues of the woodpecker, chameleon, and toad, likewise, afford examples of special contrivances for the prehension of food, each possessing the power of being suddenly protruded and withdrawn again into the mouth. In the woodpecker, the tongue is supported on a hyoid, or lingual bone, which is bifurcated backwards, and extended, by cartilaginous prolongations, along two grooves on the back of the cranium; these prolongations being drawn forward in the grooves, by proper muscles, the tongue is rapidly extended, and is again retracted by other muscles. In the chameleon, the tongue lies in the interior of a fleshy sheath, composed of circular muscular fibres, by the contraction of which, the tongue is extruded from the mouth, from which position it is again withdrawn into its sheath, by a proper retractor-muscle. In the toad, there is a partly similar contrivance; but the tongue, in a state of rest, is bent backwards upon itself, and is rapidly unfolded forwards, at the same time that it is protruded from the mouth. The suckers, or organs of attachment, found in the remora and similar fish, by which they attach themselves as parasites to the whale, or other marine animals, are also prehensile in their character; but for purposes of general prehension, fishes must use their very mobile jaws, the fins never acting in that capacity.

In the soft Mollusca, a prehensile apparatus, by which they hold to foreign bodies, or seize their prey, is frequently present, consisting of tentacula, or arms, which surround the opening of the mouth. In the Cephalopods, these attain their greatest development, being strong muscular organs, provided on their inner or holding surface with numerous discoid, cup-like suckers, the centres of which can be retracted, after they are applied to any foreign body, and so bring atmospheric pressure into exercise upon their margins. The tentacula of other Mollusca and Molluscoida, are much smaller and more delicate organs.

In the Annulosa, prehension is also accomplished by appendages connected usually with the anterior segments of the body, and forming either claws, as in the Crustaceans, or the various forms of mandibles, or jaws, seen in those creatures, as well as in the Insects, Spiders, and Myriapods. Even in the softer Worms and Leeches, prehensile power, confined to the mouth, is well provided for by special horny, or calcareous teeth. The prehensile power of the Annuloida is either buccal, as in the Entozoa, or suctional, as in some Echinodermata, or is performed by long arms, as in others.

In the Cœlenterata, prehension is accomplished by means of tentacula, situated around the mouth; sometimes highly numerous, short, and powerful organs, as in the Sea-anemone; sometimes delicate, elongated, and fringed tentacula, as in the Medusæ, Beroe, and Hydra. Most of the Cœlenterata have their tentacula furnished with the stinging organs already elsewhere mentioned.

The Protozoa can scarcely any of them be said to possess prehensile organs.

Expression and Gesture in Man.

The chief seat of expression in the human body, is undoubtedly the face; but, it must be quite understood that no

part of the body is exempt from the liability to undergo movements, which are true manifestations or expressions of internal emotions. Thus, the respiratory muscles are also excited to contract in crying, sighing, sobbing and laughter. The hand is firmly closed, and the foot is stamped on the ground in rage; the whole frame is erect, and the attitude and gestures are firm under a spirit of defiance; whilst the knees are bent, and the body droops under the influence of fear. The teeth, too, are clenched or opened, in passion or in fright, the movements of the jaws necessary to produce this effect, being caused by the muscles of mastication, not by the proper facial muscles. But it is these latter, together with the muscles of the eyeballs, which are chiefly and remarkably dominated by the passions or emotions, or by the voluntary imitation of these, in the case of the actor. The precise mode in which the eyeballs are moved in different directions, will be explained in the chapter on the Senses. As regards the muscles which co-operate to produce any special expression in the face, space does not allow us to particularise them. It is noticeable, however, that they belong to that class of muscles which are attached to bone by one end only, the other end being fixed to the soft parts, that is to the skin, so as to pull the integuments in various directions, and produce folds contrary to the line of direction of the muscular fibres themselves: thus, the horizontal wrinkles on the forehead, are produced by the contraction of a muscle (frontal portion of occipito-frontalis), the fibres of which pass vertically down to the eyebrows; whilst the folds produced at the outer corner of the eye in strong laughter, are the result of the contraction of the subcutaneous muscle (orbicularis palpebrarum), the fibres of which pass elliptically, around the opening between the eyelids. The muscles of the face are under the control of a special nerve, called the facial nerve, distinct from the one which supplies the muscles of mastication.

Expression and Gesture in Animals.

There can be no doubt that these are more actively manifested in the Anthropoid apes and monkeys, than in any animals lower in the scale; the attitudes, grimaces, and imitative acts of those creatures, nearly, and sometimes painfully, mimic those of man, and the mechanism of their production is similar. In the other Mammalia, the faculty of expression, however, and of facial expression too, is by no means absent; but by various actions, such as stamping, scratching, pawing, or wagging of the tail, by leaping or slinking movements, they manifest distinctly, and

systematically, their various emotions; whilst the change of feature in the countenance, for example, of the lion or tiger, or of the horse, exemplifies the possession of facial expressional power. In many mammalia, the eyeballs become prominent during emotion.

Passing from these to the lower vertebrate animals, features properly so called, or at any rate, movable features, consisting of a soft integument acted upon by subjacent bands of muscle, cease to exist. In Birds, these are replaced by the immovable horny bill, and by feathers which conceal all parts of the head, with the exception of the eyelids and eyes; the feathers of the head and neck, and those around the ear, are capable of being raised under excitement. In the hard-skinned Reptiles, as in the snakes, there are not even eyelids, the common horny integument passing like a fixed watch-glass, in front of the eye, whilst even in the saurian and chelonian group, the eyelid is the only movable feature. The same is the case even in the softer-skinned Amphibia. In the Fishes, the features are still more simple, the surface of the face being little more than a reproduction of the forms of the skeleton beneath, with a few muscles moving the upper and lower lips. In all these cases, from the Bird downwards to the Fishes, we miss, if not the movable cartilaginous eyelids, at least the variously formed cartilage-supported ears, the cartilaginous and movable nose, the fleshy lips, and the soft and movable cheeks: and accordingly, facial expression, reduced in its resources, becomes more and more feeble, or fixed, as we descend in the scale.

To the naturalist, instances of actions and motions, which may be interpreted as belonging to the category of expressional movements, will readily recur in the case of the Molluscous, Annulose, and even lower animals. We allude to such movements as the retraction of the tentacles of an alarmed cuttle-fish or sea-anemone, the defiant attitudes of many insects when annoyed, and the rolling up of the oniscus or woodlouse, and other insects, or of spiders, on the approach or contact of foreign bodies, movements apparently intended to imitate death; but these, and other like movements, are instinctive acts, destitute of that element of internal perception or self-feeling, which prevails in true emotional or volitional acts of expression.

In man, and in certain animals, there is one mode of expression, which is so peculiar and important, that it requires to be considered apart, viz. the production of vocal sounds as exponents of the feelings, emotions, and desires. Speech is a further prerogative of man.

VOICE AND SPEECH.

The Organ of Voice.

THE special organ of voice in man, is that portion of the air-passages called the *larynx*, a sort of hollow chamber, which extends from near the root of the tongue to the first ring of the trachea.

The larynx, fig. 9, *l*, is placed in the middle line of the neck, where it forms a considerable projection, larger above

than below; it is suspended from the hyoid bone, *h*, by muscles and ligaments; its cavity communicates with the pharynx, *p*, above, and with the trachea, *b*, below. Although the larynx is the proper organ of voice, yet the lungs and the movable and moving parts of the thorax, serve to propel the necessary air through this organ; whilst the air-passages and cavities above it, including the pharynx, mouth, and nasal cavities, assist in modifying the vocal sounds, and are therefore adjuvant and supplementary organs of voice.

Fig. 55.

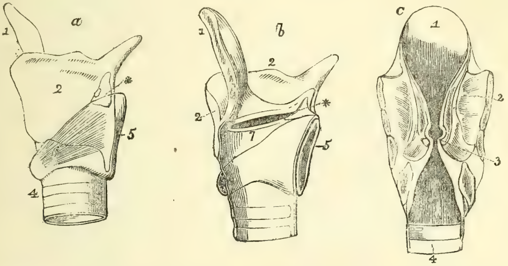


Fig. 55. Three views of the dissected human larynx. *a*, left side of the larynx, showing the cartilages; 1, the epiglottis; 2, the thyroid cartilage, its left ala or wing; 4, upper rings of the trachea or windpipe; 5, the cricoid cartilage; 6, the left crico-thyroid muscle; *, the position of the left arytenoid cartilage, shown by a faint outline; *b*, the inner side of the right half of the larynx, which is supposed to have been divided longitudinally down the middle line; 1, section of epiglottis; 2, 2, right half or ala of the thyroid cartilage; 5, ditto of cricoid; 7, right true vocal cord; above this, is the long opening of the ventricle of the larynx, above that, the false vocal cord; *c*, perpendicular section across the larynx, showing the posterior surface of the anterior half of the organ; 1, hinder surface of the epiglottis; 2, section of the right half of the thyroid cartilage; 3, section across both the vocal cords, and the intermediate chink, or glottis, with the ventricles of the larynx above them; 4, anterior part of the trachea.

The framework of the larynx is made up of cartilages, which are connected together by ligaments, and furnished with muscles, extrinsic and intrinsic; the whole organ is of course supplied with bloodvessels, nerves, and lymphatics; its interior is lined by a highly sensitive mucous membrane.

The *cartilages*, which constitute the basis of the organ, are four in number; viz. the cricoid, thyroid, and the two arytenoid. The *cricoid*, fig. 55, *a*, *b*, 5, fig. 56, B, 5, which

resembles a signet-ring placed vertically, with its broader portion turned backwards, forms the base or lower part of the organ. On the summit of the posterior border of the cricoid, are the two *arytenoid* cartilages, one on each side, figs. 55, 56 *; these are two small pyramidal pieces situated close to each other, and connected with the cricoid cartilage by means of true ball and socket joints. Each presents at its base, an anterior and a lateral process. As we shall hereafter see, they are most important structures in the production of the voice. The *thyroid* cartilage, 2, 2, rests upon the fore part of the cricoid; it is the largest cartilage in the larynx, covering the others in front and at the sides. It consists of a broad, cartilaginous plate, forming two wings or alæ, united at an acute angle in the middle line in front, where it forms the projection called the *pomum Adami* or *Adam's apple*, fig. 9; its right and left hinder borders terminate, above and below, in little processes; of these, the two upper ones, called the *superior cornua*, serve to connect the cartilage, by means of ligaments, with the hyoid bone; and the two lower ones, called the *inferior cornua*, present each a small, smooth, oval surface for articulation with the cricoid cartilage. The cartilages of the larynx are composed of pure cartilage; in advanced age, they frequently undergo partial ossification.

Behind the tongue, and in front of the upper opening of the larynx, is a curved, upright, fibro-cartilaginous plate, named the *epiglottis*, fig. 9, *e*, figs. 55, 56, 1; it is leaf-like in shape, and acts as a safety-valve, preventing the intrusion of any foreign bodies into the larynx during the act of swallowing.

The inferior or tracheal opening of the larynx is small, and roundish; but the superior or pharyngeal opening, fig. 56, is larger, and triangular in form, being wide in front and narrow behind. It is bounded on the sides by two folds of mucous membrane, which pass from the arytenoid cartilages* forwards, to the side of the epiglottis, 1, which may be said to form its anterior boundary. On looking down through this opening, two folds of the lining membrane are seen passing from the arytenoid cartilages behind, to the receding angle of the thyroid cartilage in front; these are the *superior* or *false vocal cords*, so named because they are not concerned in the production of the voice. Below these, and extending from the small process or projection on the fore part of the arytenoid cartilage, to the recessed part of the thyroid cartilage,

are the *true vocal cords*, fig. 55, 56, 7, the essential organs of voice; they are made up chiefly of yellow elastic tissue, covered by mucous membrane; and they form two sharp ridges or projections, having very fine and smooth edges, turned towards each other, and placed accurately on the same level. Between the true vocal cords, fig. 56, is a narrow, somewhat triangular interval or fissure, wider behind than in front, called the *glottis*, or *rima glottidis* or *chink of the glottis*; in man, it is about eleven lines in length, and nearly half an inch in width at its widest part; its measurements in the female, are two or three lines less; at its hinder part, or base, the triangular fissure is bounded by the arytenoid cartilages,

A Fig. 56. B

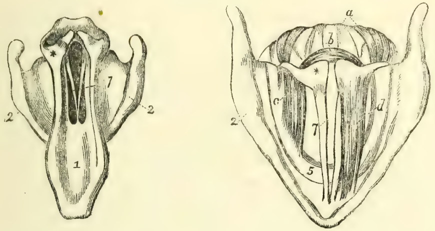


Fig. 56. Two bird's-eye views of the larynx, the back part of the organ being turned towards the top of the page: the left-hand figure, A, has the mucous membrane partly left on; the right-hand and large figure, B, is dissected, to show the muscles and separated vocal cords. In the former figure the epiglottis is marked 1, the thyroid 2, 2, the right arytenoid *, and the vocal cords 7; between them is the glottis, or rima glottidis or chink of the glottis; outside them are the ventricles of the larynx. In the left-hand figure, *a* is the posterior crico-arytenoid muscle; *b*, the arytenoid muscle passing across the middle line; *c*, the lateral crico-arytenoid muscle; *d*, the thyro-arytenoid muscle; 7, the right vocal cord. 2, is the thyroid cartilage; 5, the cricoid; *, the right arytenoid.

on either side, for the vocal cords do not extend so far back. This hinder part of the fissure is called the arytenoid portion. Above each true vocal cord is a cavity on either side, named the *ventricle of the larynx*, fig. 55; this leads, anteriorly, into a pouch of the mucous membrane called the *laryngeal sac*, the surface of which is scattered over with sixty or seventy mucous glands, the secretion from which serves to maintain the vocal cords, and surrounding parts, in a moist condition.

Connected with the laryngeal cartilages, are several small muscles, which, with one exception, exist in pairs. The *crico-thyroid* muscle, fig. 55, *a*, 6, extends from the side of the thyroid cartilage to the cricoid cartilage. Arising from the side of the cricoid, and passing upwards and outwards to the lateral process of the base of the arytenoid cartilage, is the small *posterior crico-arytenoid*, fig. 56, B, *a*. The *lateral crico-arytenoid*, *c*, passes backwards and upwards, from the cricoid to the lateral process of the arytenoid cartilage. On the outer side of each vocal cord, and lying parallel with it, is the *thyro-arytenoid* muscle, *d*, which extends from the recessed angle of the thyroid cartilage, to the base of the corresponding arytenoid cartilage. The *arytenoid*, *b*, is a single muscle connected with the posterior surfaces of the cartilages of that name.

The *mucous membrane* of the larynx is covered in the greater part of its extent with a columnar, ciliated epithelium; but the vocal cords, and the mucous membrane above them, except for a short distance in the middle line anteriorly, are covered with epithelium of the squamous variety. It is continuous above, with the membrane lining the mouth and pharynx, and below, with that of the trachea, and, with the exception of the parts covering the vocal cords, is studded with mucous glands, the secretion of which keeps the surface duly moistened; on the epiglottis these glands are very numerous. Its *nerves* are derived from the superior and inferior laryngeal branches of the pneumogastric, together with filaments from the sympathetic. The inferior laryngeal nerve supplies all the muscles except the crico-thyroid; the superior laryngeal supplies that muscle and the mucous membrane. The arytenoid muscle is said to receive branches from both nerves. A portion of the laryngeal motor fibres of the pneumogastric are derived from the spinal accessory nerve.

The Production and Modification of Sounds.

Whenever a solid body surrounded by air, is thrown into *vibrations*, in any direction, the sensation of *sound* is produced in the ear, provided the vibrations be of a certain strength, and follow each other with a certain rapidity. It is usually stated, that if the vibrations are fewer than 8, or more than 24,000 per second, no effect is produced on the nerve of hearing; but, according to other authorities, fewer than 16 or 32 vibrations per second are inaudible; and vibrations continue to be so which number 32,000, or even 70,000 per second. When the vibrations exceed a certain high number, the distinction between two

near sounds is no longer possible; the perception of sound remaining, though not the power of distinguishing them. Bodies vibrate by virtue of the elasticity imparted to them by their molecular structure. The undulations of the air may generate sound, or sound may be communicated to the air by the vibrations of another body. For the production of a musical sound, the vibrations must succeed each other at regular intervals; if the vibrations occur at irregular intervals, only a noise results. The *pitch* of a sound is determined by the number of vibrations in a given space of time, becoming higher in a direct proportion to the rate of rapidity of the vibrations. Its *strength*, or *intensity*, depends on the extent of the vibratory action of the sonorous body. The peculiar character of a musical note, whereby it can at once be distinguished from another note of exactly the same pitch and strength, is called its *tone* or *timbre*, and is dependent on the nature and shape of the vibrating body. A sonorous body may vibrate throughout its whole mass, or in separate parts; in the latter case, these parts vibrate in opposite directions, and are separated from each other by stationary points called *nodes*, or *nodal points*.

The *stretched cords*, or strings, of stringed instruments are examples of bodies rendered elastic by tension. They emit feeble tones, unless they are connected with some resonant body. When a tense cord is made to vibrate throughout its entire length, it yields its deepest or fundamental note; if the cord be divided into two equal parts by a bridge placed under it, the note heard, when it is made to vibrate, is the octave of the fundamental note. Hence the law, that the number of vibrations of any two strings, having the same degree of tension, is, other things being equal, inversely as their length. The number of vibrations is also dependent on the thickness of the strings and their tension, being inversely as the thickness, and proportional to the square root of the tension. During the transverse vibration of a cord in its entire length, other and higher sounds than the fundamental note may be heard, produced by the vibrations of aliquot parts of the cord. These aliquot parts are called the harmonic divisions of the cord.

The vibrations of *elastic rods* resemble those of strings; but the number of vibrations is inversely as the square of the length, and directly as the thickness of the rod.

The musical sounds in simple *wind instruments*, are the result of the successive condensations and rarefactions of the air through a tube. The pitch of the note, when the column of air within a tube is thrown into vibrations, is determined by the length of the tube and the strength of the blast; being lower in a direct ratio with the greater length of the tube, and higher the greater the force of the impulse, for increase in the strength of the blast leads to the formation of nodal points. If the air, in a tube closed at one extremity, be thrown into undulations, the deepest, or fundamental, note is an octave lower than that yielded by a similar tube with an open extremity; in the latter case, a nodal point is formed in the centre of the column of air; whilst in the former, the nodal point is the closed extremity of the tube.

The essential parts which enter into the formation of *tongued-instruments* are—first, the *wind-tube*, through which the column of air is driven; secondly, the *tongue*, or vibrating body, which may be rigid or membranous; and, lastly, the *attached tube*, placed beyond the tongue.

The arrangement and position of the tongue are such, that, when at rest, but little or no air can pass through from the wind-tube; but when a column of air is driven through the latter, the tongue yields in the direction of the attached tube, and an opening is thus established for the outward passage of the air-current. The rapidity with which the tongue at first yielded to the impulse communicated to it, gradually diminishes, because an opening being now established for the escape of the air, it is less exposed to its action. The tongue, by virtue of its elasticity, now counteracts the force of the impulse, and has a tendency to return to its original position; in so doing, the opening becomes smaller, the backward movement of the tongue momentarily interrupts the escape of the air-current, which, now acting with increased power, again causes the tongue to recede: in this manner, a series of more or less rapid oscillations is produced, which throw the column of air in the attached tube into vibrations. The opinion generally entertained is, that the air itself is, in tongued instruments, the primary source of the sound. It is, however, maintained by some that the sounds result from the vibrations of the tongue itself, and that the impulses communicated by it to the air, merely give increased power to the sound produced by its own vibrations.

The *pitch* of the sound, i.e. the frequency of the vibrations, of an instrument with a *rigid* tongue, when unprovided with an attached tube, is dependent on the elastic strength and the length of the tongue. As in the case of elastic rods, the number of vibrations of rigid tongues is inversely as the squares of their length; thus, a tongue six inches long, vibrates four times more rapidly than a tongue, of the same material and equal thickness, twelve inches long. But the pitch of the sound yielded by a rigid tongue, is modified, when an attached tube or body is joined to it; for the vibrations of the tongue and those of the tube, though they may each produce notes differing widely from each other as regards pitch, yet, when they are connected together, their joint vibrations produce only one sound. The pitch of the note of a rigid tongue is lowered, when the force of the blast is increased. The pitch is never raised by the addition of an attached tube; moreover, it is not perceptibly modified, so long as the tube is of a moderate length. Gradual lengthening of the tube, however, lowers the pitch; the rapidity with which this lowering of the pitch takes place, gradually increases with further lengthening of the tube, until, at a certain point, the pitch becomes an octave lower. The tube is now of such a length, that, if air were propelled into it, it would produce the same fundamental note as the tongue without the tube. If the tube be further lengthened, the pitch of the note is, at first, the same as that of the tongue; but still further lengthening of the tube, again lowers the pitch, now, however, only to a fourth; and so on.

The action of *membranous* tongues is, however, of greater immediate interest to the physiologist. These tongues, unlike rigid tongues, which, as already stated, behave in their vibrations as elastic rods, vibrate according to the same general law as stretched strings. If one extremity of a short tube be covered by two portions of elastic membrane, or vulcanised india-rubber, in such a manner as to leave a small chink between them, a form of double membranous tongue is obtained, which, in its action, bears a close resemblance to the vocal cords of Man.

Sounds are more easily produced by such a double tongue, the narrower the chink; the size of the latter, however, in no way affects the *pitch*, which is determined by the length, tension, and thickness of the tongues. The pitch of the note is heightened by touching the tongues with a firm body, a nodal point being then formed. If the two tongues have the same degree of tension, the sound emitted is of a deeper pitch than the fundamental note of either tongue. If they are subject to unequal tension, either one tongue alone is thrown into vibrations; or, if both vibrate together, two different notes may be produced; or, lastly, if they accommodate their vibrations to each other, one sound alone is emitted. The pitch of the notes produced by membranous tongues, either with or without an attached tube, is, moreover, heightened, by increasing the strength of the blast of air; in this respect, membranous tongues differ essentially from rigid tongues, in which the pitch is somewhat lowered, when the force which throws them into vibrations is increased. The pitch of a membranous tongue, combined with an attached tube, undergoes modifications closely resembling those of a rigid tongue with an attached tube. Lengthening of the tube causes the pitch to fall by semitones, but it does not sink a whole octave, as happens with rigid tongues. When a wind-tube is added to a tongue, the effects produced on the pitch, by lengthening it, are similar to those produced by increasing the length of the attached tube. Diminution of the calibre of that part of the wind-tube nearest to the tongue, heightens the pitch of the note. Partial covering of the end of the attached tube, causes a lowering of the pitch.

The Production and Characters of the Human Voice.

The researches and observations of physiologists, have long since proved that the sounds of the voice in man and mammalia, are produced by the *vibratory action of the vocal cords*, during the passage of the air through the glottis; and that these cords vibrate according to the laws which regulate the vibration of stretched membranous tongues. Experiments on living animals, show that the vocal cords are alone the essential organs for the production of voice, for so long as these remain untouched, although all the other parts in the interior of the larynx be destroyed, the animal is able to emit vocal sounds. Diseases of the larynx, in man, produce similar results. Again, if all the structures of the larynx of a dead animal, except the vocal cords, be removed, and these be rendered tense and approximated, vocal sounds can be generated by forcing currents of air through the glottis from below. If the human larynx be removed from the body, and currents of air be made to pass, from its lower end, through the glottis, sounds are also produced. By making an opening in the larynx of a living animal, so as to expose the vocal cords, the vibrations of these may be distinctly seen during the emission

of vocal sounds. The existence of an opening in the larynx of a living animal, or of man, *above* the glottis, in no way prevents the formation of vocal sounds; such an opening, if situated in the trachea, causes total loss of voice, but by simply closing it, vocal sounds can again be produced. Such openings, in man, are met with, either as the results of accidents, of suicidal attempts, or of operations performed on the larynx or trachea, for the relief of disease. Division or injury of the laryngeal nerves, at once destroys voice, the muscles which regulate the tension of the vocal cords being then paralysed. Lastly, by means of the laryngeal mirror, or *laryngoscope* of M. Garcia, the vocal cords can be seen to vibrate during vocalisation. The laryngoscope consists essentially, of a small flat metallic mirror provided with a long handle; being introduced into the pharynx, through the open mouth, it is made to receive rays of light from the sun, or from a lamp, thrown upon it by means of another large and concave mirror placed in front of the mouth; the small mirror is held with its surface at such an angle, that the rays of light are thrown down from it, upon the laryngeal opening, and so illuminate it. But the light reflected back from the larynx on to the small mirror, produces, on its surface, an image of the parts, which image is, of course, again reflected towards the larger mirror. In the centre of the latter, is a small aperture, behind which the observer places his eye, and, in this manner, some of the rays are intercepted by the eye, and a laryngeal picture is visible. By means of this instrument, which has been recently introduced into medical and surgical practice for the investigation of laryngeal diseases, the root of the tongue, the epiglottis, the projections formed by the arytenoid cartilages, part or even the whole length of the vocal cords, a part of the tracheal mucous membrane, and sometimes also the bifurcation of the trachea, are seen in form of a reversed picture on the smaller mirror. By observations thus made, it has been determined that, whilst in respiration, the vocal cords are inclined from each other, and the glottis is wide open, in speaking or vocalisation the vocal cords are seen to be approximated, and to vibrate. In ordinary tranquil breathing, the cords are widely separated, so that the glottis, which is now partly hidden from sight by the epiglottis, has a triangular form; it increases slightly in size at each inspiration, especially when the respirations are hurried and the inspirations deep; during expiration the glottis contracts. Moreover, during vocalisation, or

the production of pure vocal sounds, the arytenoid cartilages are said to become erect, and almost to touch each other; the posterior portion of the glottis between these cartilages, is quickly and completely closed, whilst the anterior two-thirds are open, so as to leave a very fine fissure; this last-named part is therefore named the *vocal* glottis, the hinder part being named the arytenoid or *respiratory* glottis. When the vocal glottis is wider than one-tenth of an inch, no sound is producible. Müller had previously shown, on the dead larynx, that the portion of the glottis between the bases of the arytenoid cartilages, is, in no way, connected with the production of the voice, for vocal sounds can be heard both when the glottis is open in its entire length, and also when its posterior part is closed; in the former case, however, the sounds are weak and difficult of production, though their pitch remains unaltered. Moreover, he found that if the anterior projections of the arytenoid cartilages be brought into contact, so as to leave an opening behind and in front of them, and air be passed through the hinder opening, no second vocal sound could be heard.

The *actions of the muscles*, which, by lengthening or shortening, by tightening or relaxing the vocal cords, or by drawing them together or apart, govern the aperture of the glottis, and so aid in the production of the voice, and modify the pitch of the notes, now require to be briefly examined.

The contraction of the two crico-thyroid muscles, fig. 55, 6, 6, right and left, draws the thyroid cartilage, 2, forwards and somewhat downwards upon the cricoid cartilage, 5; or supposing the thyroid cartilages to be fixed, these muscles would draw the cricoid cartilage backwards and upwards from the thyroid. The arytenoid cartilages, *b* *, in both cases, on account of their connection with the cricoid, are thus separated from the recessed part of the thyroid cartilage, and hence the vocal cords, 7, are both *lengthened* and rendered more *tense*. When this happens, or supposing that the principal action of the crico-thyroid muscles is to maintain the thyroid cartilage fixed in regard to the cricoid, the innermost bundles of the posterior crico-arytenoid muscles, fig. 56, B, *a*, draw backwards the arytenoid cartilage, *, and, in this manner, the length and tension of the vocal cords, 7, are still further increased. When the action of the crico-thyroid and posterior crico-aroytenid muscles ceases, the anterior and posterior points of attachment of the vocal cords to the thyroid and arytenoid cartilages,

respectively, are drawn nearer to each other, by the lateral crico-arytenoid, *c*, and especially by the thyro-arytenoid muscles, *d*; thus the cords are *relaxed*, and they become, by virtue of their elasticity, *shorter*. By some anatomists, certain fibres of the thyro-arytenoid muscles, are described as entering or mixing with the elastic tissue of the vocal cords; and these muscles are believed by them, to be able thus to tighten the cords, even when they become shortened. The lateral crico-arytenoids are, in that case, when acting alone, said merely to shorten the vocal cords, without tightening them. These two muscles may also act together.

The *narrowing* of the glottis is effected by the single arytenoid muscle, fig. 56, *b*, which, passing across the middle line, draws the arytenoid cartilages, *, together, and, in this manner, approximates the vocal cords, or may even completely *close* the glottis. Besides this, the lateral crico-arytenoid muscles, *c*, also narrow the glottis; for, by their contraction, they draw forward the lateral processes of the arytenoid cartilages, and thus swing inwards their anterior processes, *approximate* the vocal cords, and bring them into a state of *parallelism*.

With regard to the *opening* of the glottis, it may be observed that each arytenoid cartilage is, as we have seen, fig. 56, furnished with an anterior projection for the attachment of the corresponding vocal cord, 7, and with a lateral process for the insertion of the lateral, *c*, and posterior, *a*, crico-arytenoid muscles; moreover, it is so articulated on the upper surface of the cricoid cartilage, that, besides being able to move backwards and forwards, and from side to side, it can also perform a movement of rotation upon its vertical axis, that is to say upon an imaginary line passing through it from above. Hence, the outer fibres of the posterior crico-arytenoid can pull the lateral processes of the arytenoid cartilages backward, swing their anterior processes outwards, and, in this manner separate the vocal cords from each other posteriorly, and so *widen* the glottis, especially behind.

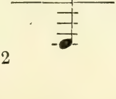
When, in tranquil breathing, the glottis is open and triangular, only a soft sound is produced by the passage of the air through its aperture; the vocal cords are at rest, but still in a certain state of tension, and not loose or relaxed; during very rapid and powerful expiration, however, a blowing or panting sound is audible, caused by the friction of the air against the walls of the air passages. The human vocal apparatus

ınalogous to a wind instrument with a *double membranous ongue*, the *bronchi and trachea* representing the *wind-tube*, he *vocal cords* the double *membranous tongue*, and the *parts ıbove the glottis* the *attached tube.* For the production of rocal sounds, even the feeblest, more air must pass through he glottis than in respiration ; and this current of air must unlergo periodic interruptions in its passage through that fissure. The vocal cords, moreover, are made more or less tense, and ıre approximated, so as to be parallel to each other, and the issure of the glottis is converted into a fine chink-like openng. The escape of the air propelled upwards through the rachea, being thus retarded, the margins of the vocal cords ıre forced upwards, and slightly separated from each other; he elasticity of the cords is now called into play, so that they ounteract the force of the impulse communicated to them, nd, by a downward recoiling movement, again narrow the lottis. In this manner, the oscillations into which the vocal ords are thrown by the escape of the air driven from the rachea, or wind-tube, are communicated to the less tense air bove the glottis, and throw this into vibrations. By means of he laryngeal ventricles or sacs, placed above the vocal cords, hese latter are kept free. so that their vibrations are easily ccomplished. It has also been supposed by some, that the uperior vocal cords maintain the strength and quality of the ounds, by entering into simultaneous and synchronous vibraions. This is contrary to Señor Garcia's observations with the aryngoscope; but he found that, in elevation of the pitch of he voice, whether natural or falsetto, the superior vocal cords pproach each other, so as to narrow the part of the vocal ube above the glottis.

The human voice, from the lowest male to the highest female oice, has a range of nearly 4 octaves, the lowest note being E*, caused by 80 vibrations per second, and the highest C † aused by 1024 vibrations in the second. But if extreme ases be included, the range is nearly $5\frac{1}{2}$ octaves, the lowest ıote being F ‡ caused by 42 vibrations, the highest A § by

†

‡



§

1708 vibrations (Vierordt). In the same individual, the compass of the voice, in singing, generally extends over 2 octaves; in some rare instances, however, it has been known to include even $3\frac{1}{2}$ octaves. In ordinary speech, the range of the voice is usually about half an octave. The production of these different notes, is effected by alterations in the length and tension of the vocal cords, and by changes in the degree of approximation and separation of these; thus, during the emission of the low notes, the cords are longer, looser, and more widely separated from each other, than they are during the production of notes of a higher pitch, and the air passes through the glottis more slowly, but in larger quantity. It has been calculated that 240 different states of tension of the vocal cords must be accurately producible at will, to account for all the notes, and intermediate tones, possible in a perfect human voice of ordinary range. The celebrated Madame Mara could effect as many as 2000 changes.

There are four different *varieties* of voice; viz., the *bass*, *tenor*, *contralto*, and *soprano*—the two former being characteristic of the male sex, the two latter of the female; there are besides, two subdivisions known as the *baritone* and *mezzo-soprano*, the baritone being intermediate between the tenor and bass, and the mezzo-soprano intermediate between the soprano and alto. The lowest note of the contralto voice, is about an octave higher than the lowest note of the bass voice and the highest soprano, about an octave higher than the highest tenor. As a rule, the bass voice possesses a lower range than the tenor, and the tenor a higher range than the bass; in the same manner, the contralto extends lower than the soprano, and the soprano higher than the contralto. These varieties of the human voice differ, therefore, in their *pitch*; this is due to the different dimensions of the vocal cords; thus, their length in the male and female, when in a state of tension, is as three to two; and, moreover, the breadth and thickness are greater in the former than in the latter.

Besides differing in pitch, the various kinds of voice differ in their *quality*, *tone*, or *timbre*, and this is a most marked difference; for a bass voice can frequently sing the higher notes of a tenor voice, and the alto the higher notes of a soprano; and yet there is a great and essential difference, in either case, between the notes produced, a difference which must be dependent on peculiarities in the form and structure

of the vocal apparatus. The difference in the tone, or timbre, of the *male* and *female voice*, is due to the great difference in the walls of the larynx in the two sexes; in the female, the laryngeal cavity is not so capacious as in the male, the angle formed by it in front, is much less acute, and the cartilages themselves are softer. The voice of *boys* is, like that of women, either soprano or alto; it is, however, louder, and possesses a different tone. The larynx presents no difference in the two sexes, until the period of puberty is reached; in boys, this organ then rapidly increases in size, the vocal cords become longer, thicker, and coarser in structure, and the voice, which at first is imperfect, and often hoarse, at length becomes tenor, or bass, finally attaining that deep tone characteristic of Man.

The general *strength* of the voice, is influenced by the capacity of the chest, the development of the muscles engaged in vocalisation, the extent to which the vocal cords can vibrate, and the power of communicating resonance, possessed by the air-passages and neighbouring cavities and sinuses. When the loudness or intensity of a vocal sound is increased, the pitch remaining unaltered, the vocal cords undergo a certain degree of relaxation, in order to compensate for the increased strength of the blast, which would otherwise heighten the pitch; this relaxation of the cords is, of course, proportional to the increased force of the air-current. Experiments on the human larynx, show that, in this manner, one and the same note can be obtained by a stronger tension and a weaker blast, as by a weaker tension and a stronger blast; these notes, although of the same pitch, differ considerably in tone, being, in the latter case, harsh and disagreeable.

The vocal sounds are further modified by the elevation and depression of the larynx; for when the voice is raised from a low to a high pitch, the whole larynx is elevated towards the base of the skull, drawing with it, at the same time, the trachea; but the mode in which the trachea and the attached vocal tube, or parts above the glottis, influence the voice, is not yet determined. The experiments of Müller on the human larynx, show that alterations in the length of the wind tube and of the attached tube, have but little or no effect on the pitch of the voice; whereas, as already stated, alterations in the length of these tubes, modify very considerably the pitch of the notes of artificial, rigid, and membranous tongues. According to this physiologist, the alteration in the length of the attached

vocal tube, produced by the ascent and descent of the larynx, is not more than an inch, and does not modify the height of the notes, the increase or diminution in the length of the tube, produced by the depression or elevation of the larynx, merely affording increased facility for the formation of the low or high notes. It is, however, maintained by some, that the total length of the trachea, with the cavities above the glottis, is in reality shortened by the ascent of the larynx, the trachea rising out of the thorax, almost as much as the larynx ascends; but, considering that the actual alteration in length is so slight as not to account for the changes in the pitch of voice, they are of opinion that a diminution in the diameter of the trachea, produced by the upward movement of the larynx, together with variations in the tension of its walls, enables it to accommodate itself to the different vocal tones. (Wheatstone and Bishop.) The trachea may, in being drawn upwards, be narrowed by about one-third of its diameter.

In the production of the higher notes of the voice, the thyro-arytenoid muscles take an active part. As already stated, the pitch of the note of a membranous tongue, is heightened, when the calibre of that part of the wind-tube nearest to the tongue is lessened. The thyro-arytenoid muscles, by narrowing the diameter of the larynx, just below the vocal cords, influence the voice in a similar manner. It was found by Müller, that on removing these muscles from the human larynx, and imitating their action, by pressing inwards the thyroid cartilage on each side, below the vocal cords, higher notes were produced. During the ascent of the voice, the soft palate is depressed, and the tonsils are approximated. The epiglottis, when depressed, is supposed to influence the pitch of the voice, causing the notes to become graver and duller, for partial covering of the end of the attached tube of a wind instrument, as already mentioned, causes a lowering of the pitch.

The peculiar tone of the voice in different persons, or the *personal quality* of the voice, is due to the form of the air-passages generally, to the condition of the mucous membrane, and to the power of resonance of those cavities: the peculiar quality of the voice, known as the *nasal* tone, is due to similar causes. If the nostrils be closed, the natural tone of the voice is not affected, so long as the arches of the palate do not approach each other; when, however, they are approximated, the nasal tone is produced; the larynx, at the same time, ascends much higher than in the production of the natural tones

The nasal tone can also be produced, when the external apertures of the nares are open, whether the mouth be closed or not; the larynx is then elevated, the palatine arches undergo contraction, the dorsum of the tongue ascends towards the palate, and the air escapes between the contracted palatal arches, the resonance of the nasal cavities alone being communicated to it. Another variety of voice, called the *veiled* tone, is produced by lowering the larynx, so that this is covered by the entire pharynx, whilst the base of the tongue is approximated to the palate, and the voice resounds in the upper part of the pharynx, beneath the skull. The resonance of the voice, is also influenced by the relative capacity and elasticity of the thoracic walls, all parts of which, especially, however, the sternum, act as resonant organs, as well as the pharynx, mouth, nasal cavities, and even the cranial sinuses and bones.

In both sexes, but especially in the male, two series of notes, differing both in pitch and quality, can be produced, viz. the notes of the *natural* voice, called the *chest* or *true* notes, and the *head* or *falsetto* notes. The former are fuller, stronger, and more resonant; the falsetto notes, on the other hand, are softer, less clear, have somewhat of a humming sound, and resemble slightly the harmonic notes of strings. The lower notes of the voice, are chest notes; the higher notes are falsetto; the middle notes of the scale can be produced alike by the chest or head voice. The transition from the chest to the head notes, takes place, in some voices, imperceptibly; in others, the change is well marked.

Various theories have been put forward to explain the manner in which the falsetto voice is produced. By Müller, the real cause of the difference between the chest and falsetto notes, was thought to be that, for the production of the former, the whole breadth of the vocal cords vibrated; whereas, for that of the latter, only their thin inner margins, or borders, are thrown into action. Another theory was, that the falsetto notes are produced, whilst the glottis is partially closed, by the vibrations of only one-half of the length of the vocal cords. (Mayo and Magendie.) The falsetto notes have also been supposed to be produced by the vibration of the cords in segments, separated by nodal points, so that harmonics of the fundamental notes are formed. (G. Weber.) It has been thought by some, that the vocal cords do not take any part in the formation of the falsetto notes, but that

these are produced by the vibration of the air itself, in its passage through the glottis, acting like the blow hole of a flute. (Pétrequin and Diday.) Lastly, it has been suggested that the falsetto notes may be formed by the division, into harmonic lengths, of the column of air in the trachea, which thus reciprocates the tone produced by the vocal cords; for, besides vibrating by reciprocation with a sounding body, the vibrations of which are isochronous with its own, a column of air may also vibrate by reciprocation, the number of its vibrations then forming a multiple of those of the sounding body. (Wheatstone.) But these more or less theoretical views are set aside by the direct observations of Garcia, who states that, during the production of the falsetto notes, the glottis is longer and wider, and that the edges only of the vocal cords are approximated, and offer little resistance to the air, whilst, in the natural voice, a certain depth of the surface of each cord is made to approach the other and to undergo vibrations; moreover, the cords vibrate more actively, the escape of air is more rapid, the notes cannot be so long sustained, and, lastly, the force of the air is weaker.

In old *age*, the muscular and nervous power are diminished, the structural elements of the larynx undergo degeneration, its cartilages become ossified, and other changes take place, which impair the strength of the voice, causing it to lose its tone, and to become weak, unsteady, and tremulous. The pitch of the voice, is modified by changes in the temperature, and by the condition of humidity of the atmosphere; in cold damp weather, it is frequently lowered by two or three notes. The voice of singers sometimes becomes dissonant; the muscles of vocalisation being fatigued, are no longer under the control of the will, and their movements become unsteady; moreover, the state of constant tension, to which the vocal cords are so frequently subject, from over-exercise, induces certain changes in them, which interfere with their healthy action.

In certain *diseases*, the lining membrane of the larynx becomes inflamed, ulceration ensues, and the voice is impaired or lost; so also in œdema of the loose areolar tissue beneath the mucous membrane of the glottis, which may be produced by inflammation of this membrane, or by any obstruction to the venous circulation through these parts, the voice is destroyed.

The glottis, besides being the organ of voice, acts as a *safety-valve*, preventing the accidental intrusion of foreign bodies, whether solid, fluid, or gaseous, into the wind-pipe.

Its sensibility, and that of the parts immediately above it, is exceedingly delicate, so that it is admirably adapted for this purpose. The moment any solid, fluid, vaporous, or gaseous noxious substance comes in contact with the upper opening of the larynx, sudden and spasmodic closure of the glottis immediately takes place; sometimes coughing ensues, and thus the body is expelled from the air-passages. The closure of the glottis is due principally to spasm of the arytenoid muscles; probably, however, other muscles are also concerned in it.

The muscles of the larynx, are placed under *voluntary*, *emotional*, *ideational*, *sensori-motor*, and *excito-motor*, or so-called *reflex*, control, by means of the superior and inferior laryngeal nerves, branches of the pneumogastric, and of the *motor* fibres given to the pneumogastric by the spinal accessory nerves. The functions of the laryngeal branches of these nerves, have been determined by numerous experiments on animals. The superior laryngeal nerve is the so-called afferent nerve of the larynx, supplying fibres to the highly sensitive mucous membrane lining the air-passages in this situation; it contains, moreover, a few motor fibres for the supply of the crico-thyroid muscle, and in part also of the arytenoid. The inferior laryngeal nerve is the efferent or motor nerve of all the other muscles. Division of the inferior laryngeal nerve, is immediately followed by paralysis of all the muscles of the larynx, except the crico-thyroid; the sensibility of the mucous membrane of the glottis, however, remains unimpaired; division of the superior laryngeal nerve causes a total loss of sensibility of the mucous membrane, whilst the movements of the glottis are unaffected. The application of a stimulus to the inferior laryngeal nerve, causes contraction of all the muscles, except the crico-thyroid, this muscle alone undergoing contraction when the superior laryngeal nerve is irritated. When the pneumogastric, or its inferior laryngeal branch, is divided, the laryngeal muscles being paralysed, the arytenoid cartilages are no longer under muscular control, but, yielding to the current of air, cause mechanical closure of the glottis, so that the animal dies asphyxiated, unless an opening be made in the trachea. Experiments on the spinal accessory nerve, show that it also has a certain control over the muscles of the larynx.

The simple reflex closure of the glottis, takes place in the case of sudden immersion in a noxious gas, when unaccompanied by sensation. The alternate opening and closing of the

larynx, in the act of coughing up an irritating body, are sensori-motor movements, being associated with sensation. The momentary closure of the glottis, when under the influence of emotion or ideas, as in sobbing or laughter, affords examples of emotional or ideational reflex movements. Lastly, the larynx is under the control of the will, as when the glottis is closed by effort, or is variously moved in voluntary coughing, or in the production of the voice and speech.

SPEECH.

Speech, or the utterance of *articulate sounds*, is a modification of the sounds generated in the larynx, in their outward passage through the cavities of the nose and mouth. Though commonly associated with the production of voice, yet it does not necessarily depend on it; for in *whispering*, for example, words are articulated simply by the action of the mouth and fauces; no vocal tones are produced, there being a total absence of laryngeal vibrations, or vocalisation, in the act. In whispering, the pitch of the sound varies in different cases, according to the natural pitch of the cavity of the mouth in each person. *Sighing* is another example of the production of sounds by the parts seated above the larynx, totally independent of any action of this organ; for when the vocal cords also are called into play, the sigh is converted into a groan. The letters of the alphabet, with but few exceptions, may be articulated without, or with only imperfect, laryngeal action, by drawing in the breath.

Articulate sounds are divided into vowels and consonants.

The true *vowels*, or *open sounds*, as they are called, are generated in the larynx. They are merely uninterrupted vocal tones, variously modified in their outward passage, by alterations in the shape of the parts of the oral cavity through which they pass; thus, in uttering the pure vocal sounds *ā*, *ă*, *e*, *o*, *u*, pronounced respectively as in the words far, fate, ell, old, and in French words containing the *u*, one and the same sound produced by the vibrations of the vocal cords is converted into five different sounds, by changes in the position of the tongue, and by the gradual prolongation of the cavity of the mouth, by means of the lips; the most natural of these vowel sounds, or the one most easily uttered, is the broad *ā*. In the same manner, the *diphthong* sounds *i*, *ei*, *eu*, and the sounds of *y* and *w*, at the beginning of words, are vocal tones,

modified by further changes in the shape and form of the mouth.

Consonants, or *shut sounds*, are entirely formed in the parts above the larynx, and are so named, because most, if not all, of them, can only be sounded *consonantly*, that is, with another sound or vowel. They require, for their production, a shutting or valve-like action to take place, either between the lips, as in pronouncing the letters *b*, *p*, and *m*; or between the upper teeth and lower lip, as in the case of *f* and *v*; or between the tongue and the palate, as *d*, *g* hard, *c* hard, *k*, *q*, *t*, *r*, *l*, and *n*; or between the tongue and teeth, as in the production of hissing sounds, such as *c* soft, or *s*, and *z*. The *compound articulate sounds*, as *j*, or *g* soft, *ch* soft, *ch* guttural, *ph*, *sh*, *th*, *ng*, and *x*, are produced by modifications, or combinations, of some of the other pure consonant sounds. The aspirate *h* is produced by an increased expiratory effort, made with the mouth open, before a vowel or other sound.

Those consonants which are produced by, or connected with, a sudden stoppage of the breath at a certain point, the opening leading from the pharynx to the nose being quite closed, and all the respired air passing through the mouth, are called *explosive* consonants. They are of two kinds; the simple explosive consonants *b*, *d*, and *g* hard; and the aspirate explosives, *p*, *t*, *k*; these, when uttered, are unaccompanied by a vocal sound, that is, they are not attended with intonation of the voice. Those consonants which can be pronounced without a complete stoppage of the breath previous to their utterance, are called *continuous*; some of these sounds are developed by the passage of the air, with a degree of friction, through the mouth; in this way, the consonants *v*, *f*, *s*, and *z*, are produced; others are produced by expiration through the nose only, as, *ng*, *m*, and *n*. In uttering the letters *l* and *r*, the air escapes through the nose and mouth; in pronouncing the first of these, the air escapes at the sides of the tongue; in pronouncing the second, the tongue undergoes a vibratory movement. All the continuous consonants can be pronounced with a vocal sound, except the aspirate *h*; and some of them can be pronounced, either with, or without, vocal intonation. Consonants have also been named, according to the seat of their production; thus *p* is called a *labial*, *t*, a *palatal*, *n*, a *nasal*, and the Gaelic *ch* a *guttural* consonant; but this classification is exceedingly artificial and incorrect; for the greater number of articulate sounds are the result of the conjoined action of the mouth, lips, palate, and upper part of the air passage.

Many sounds can be generated in the mouth, or throat, totally independent of any laryngeal action; thus, the smacking or *clicking sounds*, which occur in some of the African languages, are produced merely by separating the tongue sharply, from the hard or soft palate; in the emission of such sounds, neither breath nor voice is requisite. Many other familiar sounds, such as *kissing*, and smacking the lips as an expression of relish, are of a similar character. *Whistling*, also, is wholly unconnected with the voice, being a true mouth sound, dependent only on breath, and resulting from the vibration produced by the friction of the air against the margins of the opening. In *laughing*, on the contrary, the sounds given forth, are true vocal tones convulsively repeated.

Imperfections of speech, such as *lisping*, *stammering*, or *stuttering*, are due to errors in the action of the organs of speech. Stammering is almost always caused by some irregular action of the nervous centres, and is chiefly produced by temporary spasm of the glottis, associated with embarrassment in other parts concerned in articulation. It may originate in nervousness, or fright, and sometimes in imitation or affectation. By patient and persevering practice, founded on an accurate perception of the erroneous movements, and their correct substitutes, or by the recovery of self-confidence, these imperfections may generally be remedied. *Dumbness* is not, in any way, necessarily connected with defective development of the organs concerned in the production of speech; for *deaf-mutes* can be taught to speak, and acquire a rude kind of language. This last is an affliction conjoint, from birth, with deafness, the ear no longer serving as a guide for the purposes of articulation. Some mutes, however, are not deaf; the absence of speech, in such cases, being due, either to a malformation in the organs employed, or else to some defect in that part of the central organ of the nervous system connected with its production. It is said that persons who have become deaf, and remained absolutely so for many years, may forget how to speak, and so become dumb.

The nature of the peculiar kind of speech called *ventriloquism*, is obscure. It was supposed by Magendie to be produced in the larynx, by variously modifying the voice, so as to imitate the changes imparted to it by distance. It has also been thought to be simply produced by articulating during the act of inspiration. According to Müller, the

sound of the voice peculiar to ventriloquism, may be imitated, after taking a deep inspiration, so as to cause the protrusion of the abdominal viscera by the descent of the diaphragm, and maintaining this muscle in its depressed condition, by speaking during a very slow expiration, performed only by the lateral parietes of the chest, through an exceedingly narrow glottis. Many attempts have been made by Faber, Kempelen, and others, to construct speaking automata, but with very partial success, the separate sounds being imitated, but not the mode of combination necessary for the production of Speech.

Voice in Animals.

The organ of voice in the different orders of Mammalia, presents various degrees of development, being, in some, highly complex in structure, in others more simple in form; but in all, presenting a general anatomical and physiological resemblance to the vocal apparatus of Man. Among the so-called Quadrumana, some are provided with large sacs, situated between the thyroid cartilage and hyoid bone; these exercise a considerable influence in modifying and increasing the resonance of the voice. The acute tone and hoarse quality of the cry in some of the monkeys of the old continent, are due to the presence of laryngeal sacs. The intensity of the voice, in some species of American monkeys, the howlers, is very great; this is dependent both on the size of the epiglottis, and on the existence of cavities of considerable magnitude in the thyroid cartilage and hyoid bone, which, communicating with the ventricles of the larynx, and with other cavities above them, called the laryngo-pharyngeal sacs, cause a remarkable increase in the resonance of the laryngeal apparatus. The bray of the ass probably depends, in great part, on the presence of two large sacs situated between the vocal cords and the inner surface of the thyroid cartilage. Among the Marsupials, some, as, e.g., the kangaroo, possess membranous vocal cords which fold upon themselves; the arytenoid muscles cannot therefore stretch them. A few Mammalia are unprovided with vocal cords, and are therefore mute, as for example, the giraffe, armadillo, and porcupine. The vocal ligaments are also absent in the Cetacea; some of these are able to utter a lowing or bellowing sound; this is produced during the act of expiration, when, the mouth being closed, they expel the water, with which that cavity has become filled in the act of feeding, through the nasal opening, or openings, in the upper part of the head: the noise produced in this act, cannot be regarded as a vocal sound. The voice of Mammalia is always in a minor key.

The vocal apparatus in Birds, differs altogether from that of Mammalia, both as regards its anatomical structure, and the manner in which sounds are produced by it. Birds are provided with a larynx corresponding in situation to that of Mammalia, presenting, however, a marked contrast in many parts of its structure; and being, moreover, totally unconnected with the production of sound. This part of the respiratory apparatus is called the *superior larynx*. The true

organ of voice, the *inferior larynx,* is situated at the lower end of the trachea, immediately before it bifurcates to form the two bronchi. It presents various modifications, both in form and structure, in the different Orders of birds; in some, it forms an exceedingly delicate and complicated apparatus; it is a double organ, except in the parrot and a few other birds, and is almost always symmetrical. It is composed of several of the lower rings of the trachea, united together, so as to form a tube, which presents, at its lower extremity, two projections, an anterior and a posterior one; passing between these, in most birds, is a slender rod of bone, called the *os transversale*, which serves to connect them together; this part of the trachea opens below by two oval apertures, into the right and left bronchi. The upper margin of the bony rod gives attachment to a fine delicate membrane, the *membrana semilunaris*, which is directed upwards; connected with its lower margin is another membrane, called the *membrana tympaniformis*, which is, in reality, formed by that part of the wall of the bronchus which is made up simply of membrane; for the bronchi, in Birds, are not formed of complete rings of bone and cartilage, joined by membrane, like the windpipe, but are only partially strengthened by bony or cartilaginous pieces, so that their adjacent or opposed parietes are membranous; and it is these parietes that form the tympaniform membrane. In some birds, this membrane is very small and rudimentary; it is highly developed in singing birds, and still more so, in speaking birds; it is continuous with the membrana semilunaris, and can therefore, when thrown into vibrations, render the latter tense. The inferior larynx is provided with special muscles, in the more perfect forms, with five pairs of muscles, the office of which is to regulate the distance between the vocal membranes, and to alter their tension by elevating the first cartilage of each bronchus; in some birds, however, the inferior larynx has no special muscles. The entire organ is absent in vultures.

The seat of voice in birds, has been shown by experiment to reside in the inferior larynx, the tympaniform and semilunar membranes being the analogues of the vocal cords in Mammalia. Division of the trachea about its centre, in singing birds, does not arrest vocalisation, although the notes emitted are, of course, rendered feebler by the existence of such an opening. Again, if the bronchi, together with the inferior larynx, be removed from the body, and air blown through them, the resulting sounds closely resemble the natural notes or cries of the bird. The absence of vocal ligaments, or cords, in the superior larynx, at once excludes all idea of its being concerned in vocalisation; it no doubt, however, exercises a considerable influence in modifying the vocal sounds. It may, moreover, be seen to move simultaneously, with the mouth during the action of the inferior larynx, in singing birds. It is yet undetermined whether the sounds produced by the inferior larynx, are the result of the vibrations of a reed- or tongue-like apparatus, or whether they are caused by the friction of a column of air against the margins of an opening. In those birds provided with a simple vocal apparatus, such as the duck, there can be no doubt that this is reed-like in character; for when in action, the margins of the membranes can be seen to vibrate, and the resulting sound is, besides, exactly analogous to that produced by elastic membranes when thrown into vibrations. An opinion has been entertained by some, that the varied and manifold tones, which singing

birds, provided with a more highly-developed inferior larynx, are able to produce, are due to sonorous vibrations in a column of air, excited by friction against the margins of the aperture of the inferior larynx, in the same manner as the sound in whistling is produced by the friction of the air against the margins of the lips; but even admitting this to be true, the vibrations of the air must, in their turn, communicate vibrations to the vocal membranes. The range of the voice in Birds is usually within an octave, but in some it is much greater. As in Mammalia, the voice is always in a minor key. The various notes are produced, not only by changes in the degree of tension of the vocal membranes, but by differences in the force of the blast of air, and by changes in the length and degree of tension of the trachea, or of other resounding parts.

The trachea presents various modifications in different birds. In some, it is much longer than the neck, forming a folded tube, which consists of a vast number of rings, as in the capercailzie, stork, crane, and wild swan; in the flamingo, these rings are said to be about 350 in number. In some birds, the trachea is wider above than below, and in others, it is dilated at various points.

In Reptiles, the vocal organs are of a more simple character than in Mammalia and Birds, though they present many different degrees of development in the various Orders and Genera. The vocal cords are absent in the true Serpents, which therefore possess no voice, properly so-called; the hissing sounds produced by them, result from a forcible breathing through a soft glottis. In frogs, amongst the Amphibia, the larynx opens directly into the bronchi, these animals being unprovided with a trachea; the intensity of the sounds emitted by the male frog, is much increased by the presence of membranous sacs at the sides of the neck, which undergo considerable distension during croaking. Some frogs possess membranous vocal cords. In others, the organs which emit sound, consist of two solid rod-like bodies, the anterior ends of which are fixed, whilst the posterior extremities are free, and are directed towards the orifice of the bronchus on either side.

Fish, when taken out of water, make a peculiar noise; this is caused by the sucking or flapping movements of their mouths or gill-coverings. A few fish, provided with an air-bladder opening into the pharynx, probably produce sounds by the compression of this organ. The tambour fish produces continued sounds when under water; its air-bladder is of large size, and is exceedingly muscular.

A certain number of Insects can produce sounds. In some, as for example, the Coleoptera or beetle tribe, the blue-bottle flies, and humble-bees, the sounds are said to result from the passage of air through their spiracles, constituting what is termed humming or purring. In others, such as the crickets and grasshoppers, the sounds are caused by the friction of file-like organs, upon the margin of membranous drums, which are formed upon the wings, and the sound is called *stridulation.* The pitch of the sound of the cricket is very high, being produced by 4,096 vibrations in a second. The noises in certain species, are dependent on the rapid movements of folded membranes, called the *timbales,* which are enclosed, one on each side, in a cavity on the under part of the abdomen, and which are moved by the contraction and relaxation of special bands of parallel muscular fibres. It was long since shown that

in the Dipterous Insects, such as the flies and gnats, which have only two wings, the buzzing sound is totally independent of the action of the wings in flight, for these may be cut off, and yet the sounds are still heard; they are produced by the rapid vibration of two lateral appendages named *halteres*, which are rudimentary posterior wings. The noise emitted by the sphinx, or death's head moth, sometimes characterised as a shriek, is also produced by the friction of parts connected with the mouth and proboscis.

The remaining and lower members of the animal kingdom, being mostly aquatic, have no vocal or even other special sonorous apparatus.

SENSATION. THE REGULATION OF MOVEMENT. THE PSYCHICAL FUNCTIONS.

NERVOUS EXCITABILITY. CONDUCTILITY. SENSIBILITY.

THE vital property of *sensibility*, which belongs to the nervous tissues, consists in the power of being so excited by various external or internal stimuli, as to produce the phenomena of sensation. But this definition does not express the whole of the vital properties of the nerve tissues; nor does it accurately define those which are concerned in the sensory phenomena alone. For example: stimuli applied to the nerves, may not only excite *sensation*, but may also induce contractions, or *motion*, in the muscles, accomplishing this, either by the direct conduction of a stimulus along a nerve, or else by the conduction of a stimulus to a nervous centre, whence it is reflected, along another nerve, to the muscles. Again, in the phenomena of sensation itself, it is necessary to distinguish between the *excitation* of a nerve by a stimulus, its *conduction* along the nerve, and its final effect upon, or reception by, a nervous centre.

The kinds of *stimuli* which will excite a nerve, are the same as those mentioned in speaking of the muscular contractility, viz.: mechanical stimuli, such as tickling, scratching, pricking or pinching, bruising, stretching, tearing or cutting; the stimulus of heat or cold; irritants and chemical substances, such as mustard, acetic acid, salt, or mineral compounds—some acting by removal of water, as sulphuric acid or chloride of calcium; others by abstracting fat, as ether; and others by solution of the albuminoid substances, such as alkalies. The action of these stimuli on the nerves engaged in sensation, differs; acids, for example, causing much pain, and but little or no muscular contraction. Light, and also

some chemical substances, produce effects without any recognisable change in the nervous substance; such are the oxygen of the blood, sapid and odorous particles, and certain products of the nutrition or waste of the tissues, as well as many medicinal and poisonous substances. Electrical stimuli, whether galvanic, magnetic, or frictional, and even the electrical currents existing in animal tissues, likewise excite the nerves. But nerve is distinguished from muscle, by being excitable through certain stimuli called vital, originating in its own substance, or acting upon it from without, such as the reflex and mental stimuli, which cannot call muscular contractions into play directly, i. e. without the intervention of nervous substance. The excitability of particular nerves is also aroused, in peculiar ways, in the exercise of the special senses, as, for example, taste and smell by chemical action, hearing by vibrations in a surrounding medium, and sight by the undulations which cause the sensation of light. Psychical stimuli also excite the nerves: whether these are ideational, emotional, or volitional, they proceed from the brain, being themselves sometimes induced by external causes, and sometimes originating primarily in the great nervous centres, from the operations of the instinct, the memory, the reason, or the will.

When a stimulus of any kind, whether mechanical, chemical, electrical, or vital, acts upon the living nervous substance, be it composed of nerve fibres, or of nerve cells, it produces an impression on that nerve substance, and excites within it some particular change; and the property, by virtue of which this takes place in the nerve substance, whether composed of fibre or cell, has been called its *excitability* or *neurility*. But the nerve substance, whether vesicular or fibrous, not only receives such an impression from a stimulus, and is excited to such a change, but it possesses the property of conducting that impression, or the change produced by it, in certain definite directions; and this property might be spoken of as *conductility*. When such an impression, or excited change, is thus conducted, or propagated, simply along a nerve-fibre, or through a nerve-cell on to a nerve-fibre, and thence to a muscle, it induces or excites, as we have seen, the contraction of that muscle, and so exercises what is called a *motor* function; but when such impression, or change, is excited in, or propagated, along a nerve-fibre simply, or through nerve-cells also, up to the common sensorium of the body, it then exercises a *sensory* function, and ends in the production

of a sensation. The anatomical seat of such sensation, so far as we are at present able to trace it, is exclusively in the nerve-cells, which therefore may be said to possess a peculiar kind of *receptivity.* Hence, though both the nerve-fibre and the nerve-cell are excitable, and may be said to possess excitability, and though both can also conduct or propagate onwards, changes excited in them by stimuli, and therefore possess conductility, yet only the nerve-cells, so far as we know, possess receptivity, or true sensibility, or, as already said, can become the anatomical seats of sensation.

It must therefore be understood, that the term excitability, employed in a general sense, includes simple excitability, conductility, and sensibility properly so called. Furthermore, the nerve-fibre is wholly incapable of being acted upon directly, by mental stimuli, whether these be ideational, emotional, or volitional; for the reaction of these mental states upon the nervous system, takes place exclusively upon, or within, the grey matter of the nervous centres, and therefore, it is fair to presume, upon or in the nerve-cells, of which that grey matter is principally composed. Hence, these nerve-cells appear to possess, beyond the simple excitability to general stimuli, conductility, and the peculiar receptivity, which is essential to sensation, a special or more exalted kind of excitability, which is called into play under mental or psychical stimuli, by the changes produced in the grey matter, in the formation of ideas, emotions and will.

The excitability of a nerve remains for a time, after its separation, by cutting or bruising, from its nervous centre; but its conductility is of course immediately destroyed. The excitability of a divided motor nerve, is at first even slightly exalted; but it then slowly diminishes, and finally disappears, the nerve itself becoming converted into cellular and fatty tissue: the nearer the point of division to the nervous centre, the quicker these changes occur. Sensory nerve-fibres, when divided, undergo degeneration, both in their central and peripheral portions; in the former, because they can no longer conduct impressions, and in the latter, on account of their separation from the central organ. Excitability is thus shown to be an *inherent* property of nerve, but requires, for its permanent maintenance, a connection with a nervous centre. It is destroyed by mechanical injuries, by chemical changes, and by very strong electrical shocks. Moderate stimulation increases the excitability; stronger stimuli weaken or destroy

it. When exhausted in regard to weaker stimuli, it may still be called into play by more powerful, or by other kinds of stimuli; a succession of different stimuli is not so exhaustive as the continuance of the same stimulus.

The sudden application of any stimulus, is one condition of its action; for the mechanical stimulus of pressure gradually applied to a motor nerve, and increased in intensity, produces no convulsions, even if the nerve be ultimately destroyed. Sudden mechanical shocks alone produce muscular contractions. Again, a ligature slowly tightened around a sensory nerve, causes merely a numbness, and at length total insensibility; whereas, if it be suddenly tied, intense pain is produced. The electrical current has been supposed to act, by causing mere mechanical disturbance in the particles of the nerve-fibres; but this view is inconsistent with the known changes in the electrical state of nerves, when acted upon by galvanic currents, or by mechanical, or other, stimuli.

The action of particular stimuli deserves notice. Thus, the influence of *chemical* stimuli upon nerves is slow, probably on account of the resistance offered by the neurilemma or sheath; they are said to act more readily on sensory than on motor fibres, the former of which are, moreover, acted upon by a greater variety of chemical stimuli. Strong solutions of ammonia, and alcohol, powerfully stimulate the motor nerves; so also do solutions of nitrate of potash and hydrochloric acid, and even very weak solutions of soda or potash. Certain powerful agents, such as bisulphide of carbon and strong mineral acids, destroy the nerve so quickly that no convulsions ensue. On injecting water into the vessels of a muscle, strong contractions take place, due, it is supposed, to the effect of the fluid on the fine terminations of the nerves (Schiff); but if water be applied to the trunks of the nerves, no movements occur. The gradual abstraction of water from a nerve, is not followed by muscular contractions; but if rapidly effected, tetanic spasms are produced. Certain poisons are found to lessen or destroy the nervous excitability, acting more or less suddenly, in different cases. Some of these, as narcotics, for example, if applied locally to a nerve, will deaden its excitability at the point of application only; but, if introduced into the blood, they operate generally. The nerves are never the channels by which poisons are conducted into the system. However the sensory nerves are affected by heat or cold, it is only changes of temperature that are recognised by

the sensorium, as *thermal effects*; but extreme heat or cold produces pain. In the frog, the motor nerves are so affected by a temperature of 130° Fahr. as to produce convulsions, but these soon pass off, through a loss of excitability, which, however, reappears on cooling of the nerve. In the other direction, convulsions are caused by exposure of the nerve to a temperature of 25° Fahr. These movements are more sure to occur when the alterations of temperature are rapid (Eckhard). The nervous excitability in the frog, is said to be exalted by temperatures as high as 113°, but a still higher temperature diminishes or destroys it. A heat of 158° is followed by complete loss of nervous power; though, by a cooling down to 122°, it is possible to restore it. *Electricity*, applied methodically, may also restore nervous excitability, although, if applied indiscreetly, it may destroy it. A proper supply of *blood* to the nervous substance, is absolutely indispensable. If the aorta of a rabbit be tied, and the spinal cord be exposed as quickly as possible, no pain is produced by even the strongest irritation of the cord; in less than a minute, the voluntary control over the muscles is lost, the hind limbs are retracted, and irritation of the spinal nerves produces no signs of pain, though, for a certain time, it will excite movements. On removal of the ligature around the aorta, sensation and, somewhat later, voluntary motion, are restored. Undue excitement exhausts the excitability of a nerve, producing numbness in a sensory part, and paralysis of motion in muscles; but rest will sometimes again restore the nervous excitability. Disuse diminishes and destroys it. Defective nutrition is at first accompanied by exalted excitability, but is subsequently followed by a state of depression. In motor nerves, the excitability is, for a short time, increased after death, this increase lasting longer in the neighbourhood of the muscle. Its disappearance after death, takes place from the nervous centres to the muscles, near which it lasts the longest.

Molecular changes undoubtedly occur in nerve fibres, when these are stimulated; and, it is said, more readily in sensory than in motor fibres, the latter requiring much more powerful stimuli. These changes are not well understood. Microscopic examination reveals no physical alteration, however powerful the stimuli applied. It has been stated, however, that quiescent nerves have a neutral chemical reaction; but that this is altered to an acid one, when they are excited. (Funke.) In the mode of their operation, nerves have been

compared to telegraph wires, as performing an *internuncial* office, or the duty of conveying impressions intended to act as messages. The motor nerves have been specially regarded as electrical *discharging* organs, but the analogy here indicated is very rude.

When a stimulus is artificially applied to a nerve fibre, it is probable that its effects are propagated longitudinally in both directions; but in the living body, stimuli are usually applied to nerve fibres either at their distal extremity, as in the various sensitive tissues or surfaces of the body, or else at their central ends, as in some of the grey ganglia, or grey masses, of the nervous centres. The effect of a stimulus applied to the distal extremity of certain nerve fibres during life, is propagated, or conducted inwards, towards a nervous centre; hence it is called a *centripetal* action, and the fibre is spoken of as an *afferent* nerve fibre; on the other hand, when the central extremity of another kind of nerve fibre receives the stimulus, the effect of this is propagated outwards towards a muscle; that is to say, a *centrifugal* action takes place, and the fibre is called an *efferent* fibre. The efferent fibres terminate in muscles, and convey the effects of motorial stimuli; hence they are called *motor* or *motory* fibres. The afferent fibres have received two different names, according to the different offices which they serve. First, some afferent fibres convey the effect of impressions to certain parts of the grey matter of the nervous centres, and then, by a reflected action, which always takes place through grey matter, stimulate certain efferent or motor fibres, which, in turn, excite definite muscles to contract; such a mode of action of the nervous system, is called a *reflex* action, and the afferent fibres concerned in it, may be called *reflex afferent* fibres, and the efferent fibres concerned, *reflex efferent* or *reflex motor* fibres. The entire nervous apparatus employed in these reflex actions, viz. the afferent fibres, the grey nervous centre, and the efferent fibres, is also spoken of as an *excito-motor* nervous apparatus; and the phenomena resulting from its action, are named excito-motor phenomena, or *reflex acts*. Secondly, other afferent fibres convey the effects of impressions or stimuli upon them, to the common sensorium, and there produce *sensations proper*; these are called *sensory afferent* fibres, or simply, *sensory* fibres.

There is no anatomical difference discernible between the sensory, reflex, and motor fibres. Even between the nerves

of common sensation, and those of the different special senses, there is no recognisable distinction, excepting as regards the comparative fineness of the fibres of the latter; but they are connected with different portions or masses of the grey matter of the sensorium. It is presumable that the difference in the functions of afferent and efferent fibres, depends on the direction in which, during life, the effects of stimuli are practically made to operate, and on the difference between the parts to which those effects are ultimately conveyed. In a motor fibre, the stimulus, or rather some state of the nerve fibre produced by it, travels outwards to a contracting muscle; in an afferent reflex fibre, inwards to a reflex nervous centre; and in a sensory fibre, inwards to a sensitive nervous centre. Sometimes in the living body, a nerve is composed entirely of efferent or motor fibres; for example, the sixth cranial nerve. At other times, a nerve is composed entirely of afferent fibres; and of these, either the greater part may be purely sensory, as in the case of the nerves of the special senses of sight and hearing, viz. the optic and auditory nerves; or there may be, with the sensory fibres, many afferent reflex fibres, as in the case of the sensory branches of the first and second divisions of the fifth cranial nerve. More commonly, both efferent and afferent fibres, that is motor, sensory, and reflex, are combined together in the trunk of a nerve, as in the case of the third division of the fifth cranial nerve, and of all the spinal nerves. As we shall hereafter see, the afferent and efferent fibres, in this last case, are separated at the roots of the nerves, which are always double, and spring from different points of the spinal cord.

The white nerve fibres are excitable by artificial stimuli, and conduct the effects produced by these at and along all parts of their course; and the grey matter likewise has the same properties. During life, however, it is the peripheral extremities of the sensory and afferent reflex white fibres, which are chiefly excitable, whilst in their course up to the sensorium, they usually act as conductors only; and, again, it is the central ends of the motor fibres, which are chiefly excitable, whilst in the rest of their course to the muscles, they usually act as conductors only. But during life, the white fibres have no power, so far as we are aware, of completing a sensation; nor do they originate, or form the source of, a motorial stimulus; these two special properties or forms of nervous excitability, are limited to the grey matter. Hence

the grey matter is said to be more highly endowed, and to constitute what are called active nervous centres. Besides being concentrated in masses, the grey matter has a more complex microscopical structure, and is more vascular than the white matter.

The conducting power of motor nerve fibres is such, that it takes a certain appreciable time for the effects of a stimulus to travel along them. The rate of conduction in the frog, has been determined by the following interesting experiment performed by Helmholz. An upright blackened cylinder, made to revolve so many times in a second by clockwork, named a *Kymographion*, has two pins brought in contact with its surface; an upper one, attached to a galvanic apparatus, serves to record the moment of entrance of an exciting current into the upper end of a long nerve; whilst a lower one, attached to the muscle supplied by the nerve, records the moment and duration of the contraction of the muscle, by rising as the muscle contracts, and so describing a curved line on the cylinder. The circumference of the cylinder, the number of its rotations per second, the length of the line described by the lower pin, *before* it begins to ascend, and finally the length of the excited nerve, furnish data for the calculation of the rapidity with which the excitability of the nerve is brought into play along it; in other words, the rate of movement of the nerve-change through the nerve. Quite recently, Helmholz has devised another, much more complicated, but more delicate apparatus, for determining this rate. In the motor nerves of the frog, at a temperature between 52° and 70°, the rate of conduction was found to vary from 81 to 126 feet per second. In warm-blooded animals, and in man, it has been estimated to be rather more than 200 feet per second. The rate of motion of an electrical current travelling along a metallic wire, has been shown to be 462,000,000 feet per second. Light travels about 40,000 miles in the same period. The rate of conduction of impressions in sensory nerves, has been calculated by Hirsch, at about 110 feet per second. The same observer states that the rate of propagation differs in regard to the nerves of touch, hearing, and sight; but the numerical results obtained by him are variable. Some difference, however, may exist in different nerves, for contraction of the iris in rabbits occurs quickly on irritation of the third cranial nerve, but more slowly after irritation of the fifth. (Budge.) The rate of propagation is moreover influenced by

the strength of the stimulus, for powerful irritation of the ganglia belonging to the so-called sympathetic nerves, produces sudden reflex movements, although the normal character of the sympathetic, is to act more slowly under the influence of moderate stimulation.

It has even been observed, in certain experiments, that muscular contraction takes place more slowly, the more distant the point of nerve which is excited; and the amount of difference in time, compared with the difference between the excited points of the nerve touched, enables the rate of propagation to be estimated. The *effect* of the stimulus upon a muscle has been shown to be greater, according to the length of nerve between the point excited and the muscle. Speaking generally, the force with which a muscle, excited through its nerve, contracts, is proportional to the force or intensity of the stimulus applied to the nerve. When one nerve is excited, a neighbouring nerve lying close alongside it, may be affected, and so groups of muscles may be called into play. If a muscle be loaded with a certain weight, the commencement of contraction, when it is excited through a nerve, is somewhat delayed.

Nerves have been supposed to conduct impressions after the manner of the propagation of vibrations in tense cords, or by undulations in the fluid contents of the nerve fibres, or through the agency of an imponderable ether; but such views are entirely speculative.

Electrical Phenomena in Nerves.

Nerves, like muscles, are conductors, though not such good conductors, of electricity; like muscles, they have electrical currents passing through them, even through small portions of them, during life, when they are in their normal condition, and in a quiescent state; and, lastly, like muscles, they are as excitable by electrical currents, as by any other stimulus. But nerve is distinguished from muscle, not only by being a feebler conductor of electricity, but by exhibiting various peculiarities of behaviour, especially as regards its intrinsic electrical currents when under the influence of other extrinsic exciting currents or other stimuli. The *proper nerve current*, discovered by Du Bois-Reymond, exactly like the muscular current, runs *within* the nerve, from the interior to the surface; and there is, by analogy, ground for concluding that outside the nerve, it also passes, like the muscular current

from the surface to the cut ends; hence, in a separated portion of nerve, the surface is positive and the ends are negative, currents, as indicated by a galvanometer, passing from the equator in each direction, to the ends of the cut piece. The nerve current may be shown, by placing a portion of the divided sciatic nerve of a frog, still connected with the leg, with its surface in contact with one cushion of the apparatus already described (p. 167), and its cut end with the other cushion. In a completely separated portion of nerve, the current is equally evident, whether the peripheral or the central cut end be brought against one cushion, whilst the surface touches the other; and the effect is much increased by doubling the piece of nerve, and applying both cut ends to one cushion, and the centre of the loop to the other. The nerve current is, however, more difficult to detect than the muscular current, being many times weaker; but, as in the case of that current, it must be remembered that only a portion of the proper current of the nerve operated upon, or, as believed by Du Bois-Reymond, only a secondary *derived* current, can be made to pass through the circuit of the galvanometer. The nerve current ceases in the dead nerve. Budge alone regards it as an artificial current, of doubtful existence in the living nerve; but its presence is, by others, universally admitted. To explain this electrical condition of the living quiescent nerve, its ultimate molecules have been supposed, as in the case of muscle, to be either single molecules with a *peripolar* arrangement, that is to say, with an equatorial positive band all round them, and with the two extremities negative (Diagram D); or else to be composed of a series of double molecules, having their corresponding poles placed towards each other (Diagram F, *a*). When a nerve is excited to action, its normal current, like that of muscles, undergoes a diminution, and this takes place whether the stimulus be galvanic, or mechanical, or chemical, such as salt and strychnia. This is most evident, when interrupted electrical currents are used to stimulate the nerve, and the muscles are tetanised. According to Du Bois-Reymond, the current may even be reversed; and a portion of a nerve so altered, has its cut ends neutral or positive to the longitudinal surface, instead of negative. In this condition, the conducting power of the nerve is lessened. The nerve regains its normal conditions, on being placed for a time between pieces of muscle.

The resemblances between nerve and muscle, in regard to their electrical currents, however, are not complete; for the

electrical condition of a nerve is capable of being altered in a peculiar manner, by the application of a continuous galvanic current, which we shall here speak of as the *exciting current*, to a distant portion of the nerve; for, in such case, the normal current is altogether changed, according to, and in obedience with, the direction of the exciting current. If, for example, a portion of a nerve, Diagram E, 1, *a*, is connected with the galvanometer, by being placed on the moist cushions of the

Diagram E.

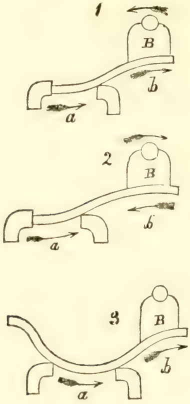


Diagram E exhibits the experiments by which an altered condition, called *electrotonus*, is shown to be produced in a nerve. 1, *a*, portion of nerve placed on the cushions of the galvanometric apparatus, *within* which piece of nerve, the normal current passes, as shown by the arrow; *b*, portion of the nerve beyond the apparatus, stimulated by a constant current from a cell B, in the direction indicated by the upper arrow, and therefore producing in this part of the nerve a current in the direction of the arrow *b*, i. e. *corresponding* with the normal nerve current at *a*. The result is to *increase* the force of the current in the part *a*. 2, *a*, as before; *b* shows the course of a constant current made to pass from the cell B, through the outlying part of the nerve, running in the *opposite* direction to the normal current produced in the part *a*. The result is to diminish the force of this latter current in *a*. 3 shows a nerve so placed on the cushions, that no current passes through the galvanometer from the part *a*; but when a constant current is made to pass through the part *b*, from the cell B, then a current in the *same* direction is generated in the part *a*, as shown by the arrow.

apparatus, represented in Diagram A, the normal nerve current passes *within* the portion of nerve, *a*, in the direction of the arrow, i. e. from the cut end to the surface of the nerve.

When now a constant exciting current is applied to *another part* of the nerve, by means of a galvanic cell B, in a direction, as marked by the arrow, *b*, corresponding with that of the nerve current in the part *a*, then the strength of this latter current is increased; but if, as shown in 2, the direction of the exciting current at *b* is opposed to that of the normal current in *a*, then the strength of the latter is diminished. Furthermore, if, as in 3, a portion of nerve is placed on the cushions, with the points of contact equidistant from its centre, so that the normal nerve currents passing from the middle or equator towards the ends or poles of the nerve counterbalance each other, as is well known, no effect is produced on the galvanometer needle; but when an exciting current is passed, as from the cell B, upwards or downwards, through a portion of the nerve as at *b*, beyond the portion included in the galvanometric circuit, then a current is immediately manifested in the part *a*, included in the galvanometric circuit, flowing, as shown by the two arrows, in a direction corresponding with that of the exciting current. In other words, the electrical condition of the *whole* piece of nerve, and not only that of its excited portion, is altered by and *obeys* the direction of the exciting current. To explain the controlling influence of the exciting current on the normal nerve current, the molecules of the nerve are supposed to be thus affected. As already stated, these are assumed to be, in the quiescent state, either *peripolar*, Diagram D, or to be composed of pairs of unipolar

Diagram D (repeated).

Diagram D is here repeated, as it shows the supposed *peripolar* condition of the nerve-molecules, as well as of that of the muscle-molecules, on which the normal current of those tissues is said to depend.

molecules, with their corresponding poles turned towards each other, Diagram F, *a*; but under the influence of the exciting currents, they are supposed by Du Bois-Reymond to be so acted on, as to become *dipolar*. On the former supposition, of the nerve consisting of rows of single peripolar molecules, a shifting or alteration of their polarity is assumed to occur; but, on the latter supposition, every other molecule is imagined to undergo a change in its polarity, or seems to turn half-way

round, as shown in *b*, Diagram F. This new condition of the nerve, as regards the electrical state of its molecules, is spoken of as its *electrotonicity*.

Diagram F.

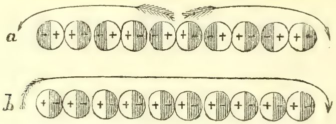


Diagram F shows a further view of the supposed electrical constitution of the nerve molecules, and also of the change in them, supposed to be produced in the state of electrotonus, or the electrotonic condition of nerves. *a* shows the supposed double constitution of the nerve molecules, each pair making up a composite peripolar molecule in the normal nerve. *b* shows how, by the half revolution of every other molecule, the whole chain may obey the direction of an exciting current or stimulus, and become *electrotonic*, i. e. its molecules may assume the electrical character of those in any ordinary galvanic circuit. The arrows show the direction of a current outside such rows of molecules, as it would pass through a galvanometric circuit connected with them.

This *electrotonic* condition is so important, that we are justified in again comparing the effects of electricity on muscle and nerve, so as clearly to impress upon the mind this distinction between those two important tissues. When a muscle is excited to contract by any kind of stimulus, its normal electrical current is simply diminished; even if the stimulus be itself electrical, no other result seems to happen, and no further alteration of the electrical condition of the muscle takes place. But in regard to nerve, besides the diminution in the proper nerve current, which takes place as the result of the application of all kinds of stimuli, the electrical stimulus, when applied to a part of a nerve, by means of a continuous galvanic current, not merely diminishes the normal current through that part, but induces a particular and obedient change in the electrical polarity of the nerve molecules of the neighbouring parts also, and thus throws not only the excited portion, but the neighbouring portions likewise, above and below, into the electrotonic state. It is more marked when the exciting current is strong; and less so, the greater the lengths of the excited portion of the nerve. It is also more perfect in the portions of nerve immediately preceding or succeeding the part excited; it becomes weaker, as the distance

from that part increases upwards or downwards, and at last it disappears in both directions, the normal nerve current pursuing its usual course.

But not only is the occurrence of electrotonicity in a nerve, a character which distinguishes that tissue from muscle; but what is even more important, certain changes in the characteristic physiological property of the nerve, that is to say, in its excitability to stimuli, or its conducting power, simultaneously take place. Thus, when an exciting current, Diagram G, B, is passed through a portion, *a*, of a nerve, going to a muscle, *m*, so as to produce the electrotonic condition above and below it, the portion, *c*, of the nerve, lying outside

Diagram G.

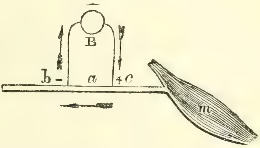


Diagram G illustrates the phenomena of anelectrotonus and cathelectrotonus; and the changes in the physiological property of excitability of a nerve, accompanying those states. *a* is a portion of a nerve, supposed to be distributed to the muscle, *m*. B, is a cell giving a constant current in the direction of the arrows, and passing through, from the anode, or positive pole +, to the *cathode*, or negative pole —, through the part of the nerve *a*. The part of the nerve marked *c*, is said to be in the state of *anelectrotonus*, and has its excitability diminished; the part marked *b*, is said to be in a state of *cathelectrotonus*, and has its excitability increased. In the portion of the nerve marked *a*, the excitability is heightened in the neighbourhood of the part *b*, and lowered in the part near *c*. Somewhere between *b* and *c*, is a point where no change in the excitability occurs.

the excited part, which is next to the *positive* pole +, and therefore *behind* the point of entrance of the current, has its excitability or its power of conduction *lessened* or diminished, whilst the portion, *b*, of the nerve next to the *negative* pole —, and therefore *in front* of the point of exit of the exciting current, shows an *increase* or heightening of its physiological properties. In other words, of the two parts of the nerve beyond the current, the part, *c*, next the entering current, has its properties diminished, and the part, *b*, next to the point of exit of the current, has its properties heightened. As the positive pole of a galvanic circuit is called the *anode*, the electrical condition of the nerve near that pole is called *anelectrotonus*, and manifests a lessening of the excitability; whilst,

as the negative pole is called *cathode*, the condition of the nerve at that part, is named *cata-electrotonus*, or *cathelectrotonus*, and exhibits a heightening of the nervous irritability. Between the two poles, *a*, the nerve is also similarly affected; the part nearest *b*, has its excitability exalted, and the part nearest *c*, has it lowered. Somewhere in this piece of nerve, is a point where no change occurs. The position of this point moves nearer to the negative pole of that current, as the exciting current is made stronger, until the whole piece of nerve, *a*, has its excitability diminished; whilst, as the current is made weaker, this point travels towards the positive pole of the current, until the excitability of the whole piece, *a*, is heightened. It has further been proved that the excitability or conductility of an electrotonised nerve, is not only lessened or heightened in intensity, but that it responds to stimuli generally, more slowly than in the healthy nerve. Moreover, it appears that a constant exciting current of a certain strength, arrests the power of a motor nerve to produce muscular contraction by, as it were, holding in check the effect of other motorial stimuli upon the nerve. This action is called *inhibition*, and the current producing it, the *inhibiting* current. Lastly, as we shall immediately more particularly describe, an excited motor nerve produces contractions in a muscle, not during the *continuance* of its electrotonic state, but only at its *commencement* and *end*; and it appears to result from still more intimate observations, made by competent experimenters, that contraction takes place at the *moment of occurrence* of the *cathelectrotonic* state, but at the *cessation* of the *anelectrotonic* state. The power of producing these contractions in a muscle, is therefore dependent, not only on the strength of the current, but is modified by its particular direction, upwards or downwards, through the nerve. The change of state produced by irritation of nerve fibres is, moreover, sometimes propagated to neighbouring fibres, so as to excite concurrent movements or sensations; or it may even extend to neighbouring branches, or collateral nerves. Thus, if the sciatic nerve of a frog, be detached from the spinal cord, and one of its two chief branches (tibial and peroneal) be cut across, above the point where it enters the muscles, and be stimulated by electricity, the muscles supplied by the other branch contract, owing to the production of the electrotonic state, not only in those fibres of the trunk of the nerve which belong to the divided branch, but also in those which belong to the undivided branch.

The phenomena produced by the application of electrical currents to motor nerves, are very complex. The effects are more marked, the further apart, and the more obliquely the poles are brought in contact with the nerve experimented upon. The chief facts hitherto observed may be thus summarised. A uniform and constant current produces no muscular contraction; but when very strong, as already stated, it inhibits the effect of other stimuli. When a constant current is varied in its intensity, then contractions take place at the moment of variation. It is by interrupted currents that contractions are normally produced, and these generally occur both when the current is made, and interrupted, or closed and opened, i. e., as just stated, at the *commencement* and *end* of a current, and not during its steady continuance; but these phenomena are not constant, as we shall immediately see. With weak currents, the contraction occurs at the making, closure, or commencement of the current; with strong currents, at both the making and interruption, i. e. at both the beginning and end, of the current. When these interruptions of the current become sufficiently rapid, the muscle is thrown into a state of constant contraction, or is tetanised. Descending and ascending currents passed along the nerve, are otherwise called centrifugal and centripetal, or *direct* and *inverse* currents, because the former pass in the same direction as the volitional stimulus, i. e. from the nervous centre to the muscle, whilst the latter pursue the opposite course. They each produce peculiar effects in particular circumstances, either according as the current is weak or strong, or according as the limb operated upon, is attached to, or detached from, the body, or, lastly, according as the excitability of the nerves and muscles, is more or less perfect. The following table shows the results obtained by Ritter and Nobili :—

	Direct Current		Inverse Current	
	Commencement	End	Commencement	End
Limb, attached to body .		*	*	
Limb, separate, vigorous .	*	*	*	*
Limb, separate, excitability lessened . . .	*			*
Limb, separate, excitability nearly gone . . .	*			

But according to Pflüger and Heidenhain the results are modified by the strength of the currents employed, as expressed in the following table:—

Strength of Currents	Direct Current		Inverse Current	
	Commencement	End	Commencement	End
Weak	*		*	
Moderate	*	*	*	*
Strong	*	Slight		*

Valentin maintains that, with moderate currents, contraction occurs only at the closure, or commencement, of the current, whether this be direct or inverse; any other results, he refers to the effects of injury to the nerve. With stronger currents, contractions occur at both the commencement and the end, the latter being the weaker. As regards very strong currents, Valentin's observations coincide with Pflüger's. Budge, however, has found that very strong currents produce contraction, both at the moment of closure and opening, whether they be direct or inverse. The different results arrived at by equally careful observers, indicate the necessity for yet further investigations in this difficult subject.

It has been shown that the muscular contractions are more intense, the further from the muscle, i. e. the nearer to the nervous centre, the stimulus is applied; this proves either that the nerve is more irritable near its centre of origin, or that the energy of a nerve *increases* as it is propagated *onward* (Pflüger and Budge). The latter view is adopted by Pflüger.

The electromotive properties, or electric currents, of sensory nerves, are precisely identical with those of the motor nerves, and so likewise they present identical electrotonic phenomena; hence an argument is derived in favour of the opinion, that both kinds of nerve fibres may conduct impressions in each direction. But the physiological reactions of the sensory nerves are somewhat different. Thus, in their case, the strength of the current influences the result; a continuous current causes *continuous* excitement, instead of interfering with the excitability, and so arresting its motorial effect on the muscles, as is the case in the motor nerves. When the limb is separate, and the sensibility is moderate, pain is excited

through a sensory nerve, only at the end of a direct or centrifugal current, and at the commencement of an inverse or centripetal current, results which are the opposite of those observed as regards the muscular contractions (Pflüger); lastly, a constant current does not inhibit the sensorial conducting power of a sensory nerve.

The experiments which establish the numerous foregoing facts, are amongst the most difficult and refined in physiological science, and clearly prove an intimate relation between the *electrical* state and the physiological action of the nerves; but at present, the true relationship between these two conditions can only be matter of conjecture. It has already been mentioned that, in stimulating a motor nerve, a constant current produces no muscular contraction, so long as it is of uniform strength, or uninterrupted; but that a variation in the intensity of the current, or an interruption of the current, will produce contraction. Now, the result of applying any stimulus, whether mechanical, chemical, or electrical, to a nerve, is, as we have seen, to cause a *diminution* of the normal, or usual, nerve current; and such a diminution or variation in the current, it is allowable to suppose, may determine the muscular contraction. Again, when a nerve is excited by an electrical current, and thrown into an electrotonic state, we have an alteration in the static current, and, besides this, a new one established in its stead; but contractions only take place at the commencement and end of the electrotonic state, not during its continuance—that is to say, at the *interruption* of the current. If, therefore, by any process taking place in the nerve cells of the grey matter, such momentary electrotonic states may be produced, contractions would necessarily occur when it was established, or when it was interrupted. Such an explanation of the action of the nerve substance is, however, at present hypothetical. The possibility of some internal change, of an electrical character in a living tissue, influencing the excitability of a nerve, and so making the muscles supplied by that nerve to contract, is proved by the interesting experiment of causing the muscles of the so-called *rheoscopic limb* of a frog, to contract, by means of the stimulus of the altered electrical currents of the muscles of another frog's limb. The rheoscopic frog's limb consists of the hinder limb of a frog, denuded of its skin, and cut off just above the knee, but having the whole length of the sciatic nerve preserved uninjured, and still connected with the

detached leg. Such a limb, sometimes also called *galvanoscopic*, serves, when insulated by being laid on a piece of glass, for the various experiments on the motor properties of the nerve; for the muscles contract when the nerve is pinched, scratched, irritated with saline solutions or acids, or when it is electrified, in which latter case the current must be made to pass, not directly across the nerve, but along some appreciable portion of its length. But the experiment to which allusion is made above, consists in laying the projecting portion of the sciatic nerve—of course uninjured—upon the muscles of another frog's leg, and stimulating those muscles to contract, by galvanising their motor nerves at such a distance from them, and in such a manner, that no part of the exciting electrical current can directly reach those muscles. When this is done, the muscles contract, and, as we already know, this is accompanied by disturbances, i. e. by intermittent diminutions in their normal current; and hence, in consequence of these variations, they excite the nerve of the rheoscopic limb, which is resting upon them, and this, in turn, causes contractions in the muscles of that limb. Here, then, is an example of a nerve excited, so as to cause contractions of its muscles, by the agency of electrical currents occurring in a living tissue, viz. in the muscles of another frog's leg. To succeed in this experiment, it is necessary that the nerve of the rheoscopic limb be placed, not merely across the contracting muscles, but obliquely or longitudinally for some little distance upon them. A very powerful exciting battery may be made, by placing a chain of skinned frogs' legs one upon another.

Dr. Radcliffe, whose opinion on the passive nature of muscular contraction has been elsewhere mentioned, supposes that the electromotive condition of the nervous molecules, is not dependent on the existence within them, of *current* electricity, or continuous internal currents, but rather upon a *static* form of electricity. The current established through the galvanometer, by a portion of nerve, he believes to be only an *induced* current; and, to explain it, he supposes that nerves, or their nerve fibres, consist of two sets of electrical molecules—an external or *superficial* set, having their surfaces *positive*, and a *central* or axial set, having their surfaces *negative*. He further believes that the diminution or cessation of the obvious nerve current, when a muscle is in action, justifies the supposition that muscular contraction may depend, not on a direct stimulation of its fibres by the nerve current, or

on a disturbance of the muscular current, but on the suspension or *absence* of the static currents, which are present in inactive, but living, nerve and muscle. The relaxed state of the muscle, he believes to be maintained by the *presence* of the static current. The rigor mortis, he likewise supposes to depend on a similar cessation of these currents. He also explains the electrotonic phenomena of excited nerves, in accordance with his peculiar views.

Nerve Force.

The phenomena which take place in nerve fibres and nerve cells, when excited to action by any stimulus, have led to the supposition that there is manifested within them, at such times, a peculiar force, which is called the *nerve force*, or *vis nervosa*, just as the electric and magnetic phenomena produced in electric or galvanic, and magnetic apparatus, are supposed to be the result of an electrical and magnetic force, called either electricity or magnetism. Three different views are entertained respecting the nature of this nerve force. By some, it is regarded as a *special force*, proper to living nerve substance, a *vital force* wholly different, even in kind, to any other force in nature. By others, it has been considered to be the same as electricity, or a mere modification of it. A third view supposes it to be a special form of the common force of nature, correlated to electricity, and, through it, to all the other forms of that force.

In considering these views, it is necessary to bear in mind that there are many reasons why the physiological energy of nerve substance, or nerve force, is to be regarded as something different from electricity. First, if it were electricity, it would be conductible along a piece of copper or other metallic conductor; whereas, if a nerve be divided, and its cut ends be connected, by laying a piece of metal wire between them, the one portion of the nerve does not act when the other portion is excited; or, in other words, the nerve force cannot pass along the metal wire. Nerve fibres, or nerve cells, are the only structures along which the nerve force can be propagated. Secondly, cold diminishes the conducting power of nerves, for the nerve force; whereas it increases the conducting power of solids or fluids, for electricity. Thirdly, the crushing of a nerve, or tying it tight, and afterwards loosening it, interferes with the future passage of the nerve current; whereas

the mere bruising of a wire, does not stop electricity from passing through it. It may be, however, that the case of an injured nerve, should rather be compared with that of a compound telegraph wire, in which the internal copper conducting wires are broken, whilst the outer supporting coils and coverings of iron wire, rope, and gutta-percha, are uninjured. Fourthly, as has already been mentioned, the nerve current travels at an extraordinarily slow rate, as compared with that of electricity. Lastly, from careful experiments performed by Pflüger, it appears that the nerve force increases in power, in proportion to the length of nerve excited; that is to say, the effect in causing muscular contraction is greater, the further from the muscle, or the nearer to the nervous centre, the nerve is excited; and so, in the reflex action of nerves, the nearer to the peripheral ends of the nerve the stimulus is applied, the greater the effect. It would seem, therefore, that either the nerve force *gathers strength* as it passes along a nerve, or else excites the development of additional nerve force as it travels along. This peculiarity distinguishes it from electricity, which has no such power of exciting new force within a conductor, but rather tends gradually to become itself exhausted. From these various facts, it appears safe to conclude that nerve force is, at least, something different from electricity; and a force so far peculiar to living animals, and to specially organised living tissues in animals, viz. to *nerve cells* and *nerve fibres*, that it cannot be manifested, conducted, or propagated, excepting in and through those tissues. There remain, however, the further important questions, whether, and in what manner, it is related, or correlated, to electricity, and through it to the common force of nature. It has been shown by the physicist that mechanical force, producing motion, is correlated with and convertible into heat, heat into chemical force, chemical force into electrical force, and electrical into magnetic force; moreover, that each of these is correlated, and convertible into the other, or, indeed, any one of them into any other, all being thus interchangeable. Now, it is not supposed that the force acting in a nerve, is identical with electrical force, nor yet a peculiar kind of electricity, nor even physically induced by it, as magnetism may be; but that, in the special action of a living nerve, a force is generated, peculiar to that tissue, which is so correlated with electricity, that an equivalent of the one may, in some yet unknown manner, excite, give rise to, or even be converted into, the other. In this concatenation

of the several forces of nature, physical and vital, the force acting in a nerve, may also be correlated with chemical force, with the heat developed in the muscle, and even with the peculiar molecular motions which produce muscular contraction, and all its accompanying physical or mechanical consequences. Indeed, as it is more acceptable to the human mind to suppose that the quantity of force, like the quantity of matter in the existing order of nature, remains the same, and is never lost or annihilated, some such notion of the interchange of inorganic into organic, and of organic into inorganic force, must be entertained. On this view, the nerve force is, as it were, nourished from physical force, as the living substance of the nervous tissues, is fed from the inorganic materials of the dead world. The nerve force here spoken of, is, however, merely that which is set free in the exercise of the properties of excitability and conductility, in both sensory and motor nerves. But, as already stated, we must leave unsolved, the mystery of *sensation* and *consciousness*, as endowments of living matter, even when these are manifested in their simplest forms, in animals; and, in regard to the higher mental faculties, we can only recognise the co-operation of the same nerve force, as one necessary physiological condition of all such psychical phenomena in us.

The particular *functions* performed by the nervous system, are, as already stated, first, those of *sensation*, *common* and *special*. Secondly, the regulation of all the movements of the animal body, whether these be reflex, emotional, ideational, or volitional; or whether they appertain to the animal, or to the vegetative functions, such as the movements of respiration, those of the alimentary canal, and the motions of the heart and bloodvessels. Thirdly, the nervous system is that part of the frame, through the agency of which, all mental manifestations occur. Lastly, the nervous system influences the nutritive functions of the body, either solely by its effects on the minuter bloodvessels, or, perhaps also, by some special control over, or interference with, the chemical processes of nutrition and secretion.

In the lowest animals, as we shall see, the nervous system disappears; and hence all their functions, whether animal or vegetative, are performed, so far as we can at present discern, independently of nervous substance.

In man and the higher animals, not only are both the animal and vegetative functions placed, more or less, under the control of the nervous system, but the anatomical connections between the different parts of this system, are exceedingly numerous and intricate, and the physiological relation between the most distant parts, proportionally intimate. Moreover, the paths and centres concerned in the functions of sensation, reflex and other motions, and psychical acts, are so structurally associated, that all parts of the body are more or less in sympathy with each other; and even the vegetative organs, though provided with their own nervous apparatus, may be so affected through the irritation of distant parts, that a strong light applied to the eye, will cause vomiting, and an emotion or desire will create palpitation of the heart. So widely diffused, indeed, are the phenomena of sensation, regulated motion, and psychical action in the body, that it is easier, instead of describing these functions in strictly physiological order, to treat of the functions of the several parts of the nervous system. To prepare the way for such an account, we must first give a description of this system.

THE STRUCTURE OF THE NERVOUS SYSTEM.

The nervous system in man, includes the *cerebro-spinal* nervous system, and the *sympathetic* nervous system. The former consists of a central part, composed of the *brain* and *spinal cord*, often designated together, the *cerebro-spinal axis*, and of a peripheral part, composed of *nerves* which spring from the brain and cord, and are named the *cranial* and *spinal* nerves. The sympathetic nervous system consists of numerous *ganglia*, connecting *nerve cords*, and branches or nerves; it is joined, by numerous short cords, with the cerebro-spinal system.

The Cerebro-Spinal Nervous System.

The protected position of the brain and spinal cord, within the cavity of the cranium and the spinal canal, as well as the mode in which the nerves escape from those cavities, have been already described (pp. 23–4, figs. 9 and 12); and the position of the sympathetic nerves in the thorax and abdomen, is mentioned at pp. 31, 34, and is further illustrated in fig. 62.

The three protective *membranes* which cover the brain and spinal cord, viz. the *fibrous* membrane or *dura mater*, the

serous membrane or *arachnoid*, and the *vascular* membrane or *pia mater*, have also been mentioned. The *dura mater* protects the brain and cord, forms supporting partitions between the right and left halves of the cerebrum, and between the cerebrum and cerebellum, and furnishes sheaths to the several cranial and spinal nerves; it likewise assists in forming venous channels or sinuses for the conveyance of the blood returning from the brain; in the cranium, it acts as an internal periosteum. The *arachnoid*, like other serous membranes, is a doubled membrane forming a closed sac, the purpose of which is to facilitate such motions of the brain and cord, as are inevitable in changes of their position, or of the state of their circulation. The spinal cord is specially supported by a long duplicature of the arachnoid, with fibrous tissue in it, on each side, named the *ligamentum denticulatum*, fig 60, *t*. Between the arachnoid and the innermost membrane, or pia mater of the brain and cord, are certain spaces filled with fluid, the *subarachnoid fluid*, which is said to support the great nervous centres as in a hydrostatic apparatus. Its usual quantity is about two ounces, but this varies in certain circumstances; in cases of extravasation of blood in the head, it is all absorbed; whereas, in wasting of the brain, it is increased to as much as twelve ounces. In the more slightly varying conditions of the circulation in the cranium, its quantity no doubt is perpetually changing; for when it escapes in fractures of the skull, or in injuries of the spine, it is very rapidly reproduced. It may also readily descend into, and ascend from, the spinal canal; and thus, or by absorption, may regulate the degree of pressure on the brain and spinal cord. When suddenly withdrawn, great disturbance of the functions of the brain ensues, but these are restored as it is reproduced. Pressure on the brain, causes sleep, torpor or coma; and the absorption of this fluid may, to a certain degree, remove the effects of pressure. The *pia mater* is chiefly formed of a congeries of small arteries, which here ramify and subdivide, before entering the cerebro-spinal nervous centres. The supply of blood to these organs is very large, amounting, it is said, to one-fifth of the total quantity of blood in the body, though the weight of the encephalon is only about one-fortieth of the weight of the body. The peculiarities of the blood-vessels in the cranium, and the regular and uniform distribution of the blood to the brain, will be described in the chapter on the Circulation. Ligature of the great vessels of

the neck is quickly fatal, unless some collateral vessels continue to carry blood into the cranium. The snake charmers of India, sometimes produce, as a trick upon themselves or others, stupor and rigidity, by pressing below the base of the skull, probably by arresting the circulation through the brain. Rupture of the heart, or of the aorta, is followed by instant death, owing to a failure in the supply of blood to the brain. Syncope, or loss of consciousness and voluntary power, is a temporary suspension of the cerebral functions, owing to a deficient action of the heart. A decapitated head certainly may exhibit, for a time, reflex movements; but it cannot be known whether, and for how long, it retains sensibility.

The entire human brain, well named the *encephalon* (ἐν in, and κεφαλη, the head), is a solid but soft organ, which weighs, on an average, in the female, about forty-four, and in the male, about fifty ounces; ranging in the female, from thirty-nine to forty-seven ounces, and in the male, from forty-two to sixty ounces. The mean difference between the male and female brain, is about five ounces. The brain bears a general proportion to the weight of the body, and this probably explains the greater weight of the male brain; for in eighty-one males, the proportion of the brain to the body, was found to be as 1 to 36·5, and in eighty-two females, very nearly the same, viz. as 1 to 36·46. These were from persons who had died from exhausting diseases. The average proportion of the brain to the healthy body, is about 1 to 41. The brain grows rapidly up to the seventh year, and at the eighth year, appears to reach nearly its full size; then a slighter increase is observable up to the twentieth year, and even a slow augmentation up to about forty years; after fifty years, there is a slow diminution in weight, it is said of about one ounce for each decennial period.

In extreme cases, the brain has reached the weight of sixty-five ounces. (Cuvier's brain weighed upwards of sixty-four ounces.) In idiots, the brain is small, having been found to weigh from about twenty-five ounces to as low as ten ounces, in a female, forty-two years of age; and eight and a half ounces in an idiot boy, twelve years old; this is the smallest idiot brain on record. The proportionate weight of the brain to the body, in idiots, has been found as low as 1 to 144. The weight of the brain varies in the races of mankind, chiefly, however, it would seem, in harmony with their stature; for the cubical capacity of the cranium, which is a fair indication of

the size of the brain, and in the European, on an average, measures about 80 cubic inches, is in the large-bodied negro, about 70 cubic inches; in the smaller Bush tribes, about 60 cubic inches; and in the Hindoos, also of diminutive stature, though of fine organisation, it is said to be as low as 47 cubic inches.

The entire brain, or encephalon, is made up chiefly of two parts—an anterior upper part much larger, called the *cerebrum*, or *brain proper*, fig. 12, *a*, and a smaller posterior and inferior part, called the *little brain* or *cerebellum*, *b*. Besides these, there are certain connecting parts at the base, constituting the *cerebral peduncles*, the *pons Varolii*, and the *medulla oblongata*. The cerebrum and cerebellum are supported at their base, on certain stalk-like parts called peduncles, from which a sort of main stalk, formed by the medulla oblongata, is prolonged out of the cranium into the spinal canal, forming the spinal cord. The *spinal cord*, *c*, is a cylindrical mass of nervous substance, which extends from the opening in the base of the skull, down to about the lower part of the body of the first lumbar vertebra, where it becomes pointed, *c*, and terminates in a slender membranous filament, which runs downwards, and is attached to the lower part of the canal in the sacrum. The continuation of the spinal cord upwards within the cranium, towards the peduncles of the cerebrum and cerebellum, is named the *medulla oblongata*, fig. 60, *m*; it is of a pyramidal form, having its base turned upwards, and measures about one inch and a quarter in length. Just above the medulla oblongata, in front, is a broad transverse band of nervous substance, called, after an old anatomist, the *pons Varolii*; this extends laterally into the cerebellum. Issuing from above the pons, are the stalks or *peduncles* of the cerebrum; these are continuous upwards with the cerebrum, and downwards, through the pons, with the medulla oblongata and cord. The cerebellum, figs. 12 and 60, *b*, is also connected by peduncles, with the back part of the cerebral peduncles, the pons and the medulla; thus its inferior peduncles attach it to the medulla, its middle peduncles are formed by the lateral extensions of the pons, and its superior peduncles join it to the back of the cerebral peduncles.

Supposing the entire brain or encephalon to weigh fifty ounces, the cerebrum would weigh about forty-four ounces, the cerebellum five ounces, and the pons and medulla oblongata one ounce. The proportion between the cerebellum and the cerebrum is therefore about 1 to 8·8. In early life, the cerebellum

is much less developed in proportion to the cerebrum, the ratio between the two being then as 1 to 13 or 15. The cerebellum acquires its maximum weight between twenty-five and forty years of age; its rate of increase, after fourteen, is proportionally greater in the female. In idiots' brains, owing to the want of development of the cerebrum, the cerebellum is disproportionally large, the ratio having been found to be about 1 to 4, or even as low as 1 to 2·6. The spinal cord weighs usually, on an average, one ounce and a half; its proportion to the encephalon is therefore about 1 to 33. The following numbers have been stated by Bourgery, to represent

Fig. 57.

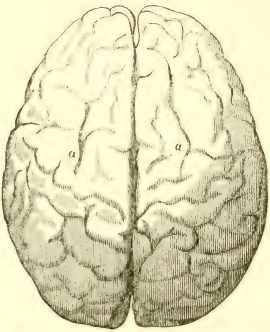


Fig. 57. Upper surface of the cerebrum of man, showing its subdivision, by the longitudinal fissure, into two lateral hemispheres, right and left; also the chief sulci and convolutions. The fissures of Rolando are the oblique fissures which commence near the middle line, and proceed outwards and forwards, marking off the frontal lobes, *a*, *a*, from the parietal lobes, which lie behind those fissures. The occipital lobes, forming the hinder extremity of the hemispheres, completely conceal the cerebellum.

the relative weights of the several parts of the nervous centres in man:—the cerebrum, 170; the cerebellum, 21; and the peduncles, and certain parts connected with them, named the corpora striata and optic thalami, with the pons Varolii and the medulla oblongata, 13. The whole encephalon is thus supposed to be divided into 204 parts.

The *cerebrum*. In considering further the structure of the great nervous centres, it is important to bear in mind the primary fact, that they are composed, cerebrum, cerebellum, pons, medulla oblongata, and spinal cord, of two symmetrical

halves, applied to, and united together, in various ways, along the middle line. Thus, the cerebrum itself, fig. 57, is composed of two lateral halves, called the *cerebral hemispheres*, *a*, *a*, which are united together, at the bottom of a deep fissure, named the *longitudinal fissure*, by a thick transverse band of nervous substance, called the *corpus callosum*, which, however, passes across, between the hemispheres, in only a certain middle portion of their extent, so that the latter, as shown on a horizontal section, fig. 58, *a*, *a*, are completely separate, in front and behind it. It is in this longitudinal fissure that the falx cerebri, fig. 9, *f*, dips down; whilst the tentorium is placed

Fig. 58.

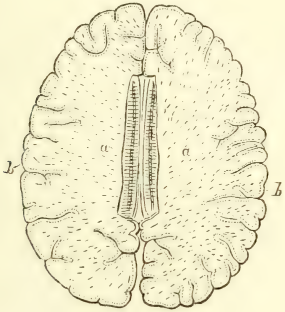


Fig. 58. Horizontal section through the cerebrum, to show the mode in which the two hemispheres, *a*, *a*, are joined together by the transverse band of white substance, named the corpus callosum. In front and behind this, the longitudinal fissure separates the two hemispheres. *b*, *b*, is the section of the cortical substance; *a*, *a*, of the medullary. The section also shows the depth of the sulci, between the convolutions.

horizontally, between the hinder part of the cerebral hemispheres and the upper surface of the cerebellum. At the base of the cerebrum, its hemispheres are further connected by their respective peduncles, which are themselves united together in the middle line. Within the hemispheres, and between the corpus callosum above, and the diverging peduncles below, are certain *cavities* in the interior of the cerebrum, called the *ventricles*; these cavities are roofed in, as it were, by the substance of the hemispheres, and by the corpus callosum, and are also closed below by the diverging peduncles, at the sides by the hemispheres, and in front by nervous substance passing down

from the corpus callosum to the peduncles; but posteriorly, they are open, so as to communicate with the surface, and admit, into the interior of the ventricles, an extension of the vascular covering of the brain, or pia mater, together with many large bloodvessels.

Each cerebral hemisphere is described as consisting of certain part called *lobes*, which were formerly named *anterior* or *frontal*, *middle* or *parietal*, and *posterior* or *occipital*. The anterior lobe was said to be separated from the middle, by a deep fissure, seen on the side of the brain, named the *Sylvian fissure*, but the limits between the middle and posterior lobes were arbitrarily fixed by different anatomists, according to their position in regard to the cerebellum. Certain well-marked fissures, which have been observed on the outer and inner surface of the hemispheres, serve however to divide its mass more definitely into such lobes. For example, one long fissure, called the *fissure of Rolando* (see description of fig. 57), passes obliquely forwards, from a little distance behind the vertex, and separates an anterior or frontal region from a middle or parietal region, the former nearly corresponding with the frontal lobe, but including a small portion of the parietal lobe. Further back, another fissure, seen on the inner surface of the hemisphere (see description of fig. 59), and called the *internal perpendicular fissure*, marks off a posterior lobe or region, which is now described as the *occipital* lobe. Below that, on the under and inner surface of the hinder part of the hemisphere, is a horizontal fissure, called the *fissure of the hippocampus*; this separates the occipital lobe above, from the lowest portion of the middle lobe, now named the *temporal lobe*, which is further separated, on the outer surface of the hemisphere, from the frontal and parietal lobes, by the Sylvian fissure. On opening out the Sylvian fissure, a fifth lobe is seen, named the *central lobe* or *island of Reil*. Of these lobes in the perfect human brain, the frontal is the largest, the temporal and parietal are next in size, then the occipital, and, lastly, the central lobe is the smallest. Each of these lobes has its surface moulded into numerous tortuous and complicated elevations of the cerebral substance, which have been named the *gyri* or *convolutions*; these are marked off from each other by secondary winding fissures called *sulci*. Most of these convolutions have long since been separately described and named by Flourens and others, but a more systematic account of them has been recently given by Gratiolet, in their

respective groups of frontal, parietal, temporal, occipital, and central. The convolutions of each lobe are connected together at the bottom of the sulci, and also more or less at their ends. So also the different lobes of the hemispheres are not distinctly severed from each other, but are united at the bottom of the divisional fissures, and also round the ends of these fissures. On the outer surface of each hemisphere in the human brain,

Fig. 59.

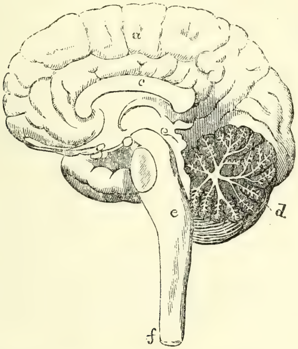


Fig. 59. Longitudinal median section through the human cerebrum, cerebellum, cerebral peduncles, pons Varolii, medulla oblongata, and part of spinal cord. *a*, inner surface of the right cerebral hemisphere, showing its sulci and convolutions; the fissure, running upwards and a little backwards, above the cerebellum, marks off the occipital lobe from the parietal. *c*, is the section through the corpus callosum, the large white commissure, which connects the two hemispheres; below this, are the ventricles of the brain, and then the cut surface of the right peduncle; the section of the pons Varolii, is the part level with the cerebellum. *d*, the section through the cerebellum, showing the branched white substance, penetrating the grey matter, and forming the so-called *arbor vitæ*. *e*, section of the medulla oblongata; *f*, the same of a part of the spinal cord.

owing to the absence of the external part of the so-called perpendicular fissure which exists more or less marked in the Quadrumana generally, the line of distinction between the parietal and temporal areas or lobes in front, and the occipital lobe behind, is obliterated by many sinuous bridges of nervous substance, called the *connecting* convolutions. The general plan of the convolutions in the two hemispheres is the same; but, in point of detail, there is a want of exact symmetry, a

character which seems to be associated with a higher development of any given type of cerebrum.

From the preceding description, it will be seen that the free convoluted surface of the cerebral hemispheres, is of enormous extent, in comparison with the small surfaces, which are connected below with the peduncles, and across, from side to side, with the corpus callosum. This free surface, indeed, occupies at least five-sixths of the internal surface of the hemispheres corresponding with the parts turned towards the longitudinal fissure; it extends likewise all over the outer surface, and over the base, with the exception of the comparatively small part connected with the peduncles. It corresponds with the internal surfaces of the frontal, temporal, and parietal bones, with a portion of the occipital bone, and with the upper surface of the tentorium.

The whole of this highly complex free surface of the hemispheres, which appear like efflorescences upon the summit of a stalk, fig. 59, *d*, is composed essentially of *cineritious* or grey nervous matter, here named the *cortical* substance, fig. 58, *b*, consisting chiefly of nerve cells, but also traversed by a number of very fine white fibres, and extremely well supplied with bloodvessels. The two principal purposes fulfilled by the superficial position of the grey matter, and by the great complication of its surface, are that of allowing a more perfect communication with the numerous fibres connected with it, and that of obtaining the greatest possible amount of grey nervous matter within a comparatively small space; moreover, this large surface facilitates the free and abundant supply of blood to the important grey cortical substance of the cerebrum. The surface of the human cerebrum has been computed by Baillarger to be equal to about 670 square inches. The thickness of the cortical substance is usually about one-fifth of an inch; but this varies, as well as the depth of the sulci, which is a measure of the height of the convolutions: in both these respects, the adult human brain exceeds that of the infant, or of the aged; and a deficiency in both, has been observed in idiots, and in the less civilised races of men. The colour and structure of the cortical substance are not uniform in its whole depth; but it presents three different zones, viz. an *outer pale zone*, in which two narrower ones may be recognised; a *middle greyish zone*, and an internal *reddish-yellow zone*, in which four narrow ones, two reddish-yellow, and two white, may be discerned, thus making *seven*

zones, or layers, in all. The nerve cells, also arranged in layers, are most abundant in the middle zone, and least so in the external one, in which the white fibres are very numerous. The nerve cells are provided with numerous branching offsets, i.e. are markedly multipolar. The white fibres of the deepest zone are chiefly radiating in their direction, but some also pass parallel to the surface of the cerebrum, and so give rise to the appearance of zones. As the white fibres proceed through the grey matter, they become finer, and many of them end in the processes of the nerve cells. In the external zone, they are finest of all, and many of them again spread out parallel with the surface, in the paler streaks of the outer zone, where they form loops, or are connected with nerve cells. The object of the intricate arrangement here described, appears to be to multiply the nerve fibres, which, by successive connection with layers of branched cells, are rendered finer, at the same time that they are enormously increased in number, and form almost infinite communications amongst themselves, and with the nerve cells.

The internal substance, *a*, *a*, of the hemispheres, named the *medullary* substance, is white, and is chiefly composed of white nerve fibres of very small diameter, which are ultimately connected with those found in the cortical substance. They may be regarded as forming several systems. First, there is a system of short *intrinsic commissural* fibres immediately beneath the grey matter, which connect adjacent or even remote convolutions. Secondly, there exists another smaller but doubtless important system of intrinsic *longitudinal commissural* fibres, which serve to connect the several lobes of each side, and also the so-called optic thalami and other parts, with the occipital and temporal lobes. The chief longitudinal band constitutes a part called the *fornix*, situated in the ventricular cavities beneath the corpus callosum; besides this, there are the *tænia semicircularis*, also within the ventricles, and certain other bands above the corpus callosum, and within the convolutions resting immediately upon it. Thirdly, there is a system of *transverse commissural* fibres, which pass from all regions of one hemisphere to the corresponding regions of the other, and form the large cross band called the *corpus callosum*, fig. 59, *c*, above the ventricles; three other small transverse commissures, *anterior*, *middle*, and *posterior*, are situated in the floor of the ventricles. Lastly, there are found fibres, usually named the *radiating* fibres, or *ascending* fibres, but which, if traced from

the cortical substance of the hemispheres downwards, may be called the *convergent* or *descending* fibres. These proceed from all parts of the superficial grey matter of the hemispheres, and converge towards the cerebral peduncles. Some of these convergent fibres have been described as crossing from one hemisphere, through the corpus callosum, to the other, and then descending towards the cerebral peduncles of that side, constituting therefore a *decussating* system of fibres; but this is not certain.

Above the cerebral peduncles are found, on each side, two large masses of grey matter, named the *corpus striatum* and the *optic thalamus*. The corpora striata lie in front of the optic thalami; both bodies partly project into the ventricular cavities, partly rest upon the peduncles, and have the rest of their surface imbedded in the corresponding hemisphere, the radiating or convergent fibres of which, coming from all directions, pass into one or both of these masses of grey matter, but especially into the corpus striatum, which hence presents a *streaked* appearance on a section, as its name implies. It was formerly supposed that the convergent fibres from the hemispheres, traversed these large masses of ganglionic grey matter, and became directly continuous with fibres in the cerebral peduncles, the pons, the medulla oblongata, and the spinal cord. But, according to the most recent view, the fibres proceeding downwards from the cortical substance of the hemispheres, do not pass continuously through the corpora striata and optic thalami, into the cerebral peduncles, but terminate in the grey substance of those ganglionic masses, from which other fibres pass down into the peduncles, medulla oblongata, and spinal cord, and so become connected with the roots of the cranial and spinal nerves. Many, at least of the converging fibres, must stop short in the grey matter of these ganglionic masses, or they would certainly form a larger peduncle to each hemisphere than actually exists, and no instance has been detected of two or more white fibres uniting, in this situation, into a single one, and so accounting for their diminution in number. The convergent or radiating fibres of the cerebrum exceed the others in number; but the large proportion which the commissural fibres bear to them, appears to be one cause of the greater size of the cerebra of the higher animals, and especially of that of man.

Besides the corpora striata, and the optic thalami, other smaller masses of mixed grey and white matter, demand at-

tention. Thus, on the under surface of each frontal lobe, is found a small elongated oblong mass of grey matter, called the *olfactory lobe*, which is attached by a narrow white peduncle, spreading backwards into three bundles, to the under surface of the frontal lobe, and to certain adjacent parts at the base of the cerebrum, in front of the Sylvian fissure; it is from these olfactory lobes, that the proper olfactory nerves, or nerves of smell, are given off to the nose on each side. Again, resting on the back part of the conjoined cerebral peduncles, overhung by the posterior border of the corpus callosum, and attached by white fibrous nervous substance, to the optic thalami, to the cerebellum, to the cerebral peduncles, and to the medulla oblongata, are four small eminences, named the *corpora quadrigemina*, two on each side of the middle line, and all blended together. They are white on their surface, but are composed of grey matter intermixed with many white fibres, running transversely, obliquely, and longitudinally: it is from these that the optic tracts, or roots of the optic nerves, or nerves of sight, chiefly take their origin. Two other little grey masses on each side, named *corpora geniculata*, are also found in connection with the tract or root of each optic nerve. Supported above the corpora quadrigemina, is a little conical body, attached by minute white pedicles, to the surface of the optic thalami; it is named the *pineal body* or *pineal gland*, and was supposed by the celebrated Des Cartes to be the seat of the soul. It is larger in the child and in the female, than in the male; it contains two or more cavities, usually filled with a viscid fluid, and gritty matter, *acervulus cerebri*, composed chiefly of aggregations of the so-called amyloid bodies, mixed with earthy and a little animal matter. The substance of the pineal body, contains pale roundish cells, and a few nerve fibres. Lastly, projecting downwards from the base of the brain, between the diverging cerebral peduncles, and connected with the floor of the ventricular cavities, is a tubular peduncle, which supports a nut-shaped mass, named the *pituitary body* or *hypophysis cerebri*. It weighs from five to ten grains, and, in the adult, is solid and firm. It is composed of an anterior larger, and a posterior smaller and deeper-coloured lobe, both, however, being very vascular. The anterior lobe especially, has been found to present a structure resembling somewhat closely, that of the thyroid body, which is one of the so-called ductless glands. (Sharpey.) In the posterior

lobe, a few nerve tubes are found. The use of this body, and that of the pineal gland, are entirely unknown.

In front of the pituitary body, the optic tracts of the two sides coalesce, or decussate, to form the *optic commissure*, from which the right and left optic nerves then proceed forwards to the eyeballs. It remains to be added, that in the interior of the cerebral peduncles, which are composed of white substance externally, there is also diffused a large quantity of grey or ganglionic nerve substance.

The ventricles of the cerebrum, mentioned so frequently above, are five in number, and were, by the old anatomists, considered of special importance, and to be the residence of what were then called the *animal spirits*; but they are really the remains of a simple cavity, formed by the folding back of the hemispheres, in the progress of their development, and gradually complicated in shape, owing to the projection of the corpora striata and optic thalami into them, and to the extension of the white cerebral substance, in various directions, round about them. As already stated, they are roofed in by the corpus callosum, and by its lateral extensions into the hemispheres; whilst in front, at the sides, and below, there are the corpora striata and optic thalami, the cerebral peduncles, and certain layers of nervous substance connecting those parts. The two largest chambers of these ventricular cavities, are the two *lateral ventricles*, right and left, one belonging to each hemisphere. Each lateral ventricle presents a central part or body of the cavity, and three prolongations named the *cornua* or *horns*, viz. an *anterior cornu* or horn, which passes into the frontal lobe, a *middle* or *descending cornu*, which curves backwards and outwards, and then downwards, forwards, and inwards, into the temporal lobe, and the *posterior cornu*, which passes backwards and outwards, and then inwards, in the occipital lobe. The descending cornu contains, besides the posterior ends of the fornix already mentioned, and other parts, a projection or ridge in its floor, called the *hippocampus major*; and in the posterior cornu, is a similar smaller projection named *hippocampus minor*; between them, is the *eminentia collateralis*. Both of these so-called hippocampi are merely portions of the hemisphere, projecting into the ventricle, and corresponding with the bottom of certain more or less well-marked fissures, or sulci, on the surface. The *third* ventricle is situated in the middle line, near the base of the brain, between the optic thalami; it communicates with both

the lateral ventricles, and with the fourth ventricle to be presently noticed. The *fifth* ventricle is a small independent cavity, situated in a septum of nervous substance, found between the two lateral ventricles.

The *cerebellum.* This part of the encephalon rests upon the occipital bone behind the foramen magnum, and is covered by the tentorium. It consists, like the cerebrum, of two hemispheres, which, however, are more extensively united than those of the cerebrum, and in a different manner, by a median portion, similarly constructed to the hemispheres themselves, and forming, on the upper and under surface, the so-called middle lobe, or *superior* and *inferior vermiform*, or worm-like processes ; a slight notch marks off the hemispheres in front and behind. Each hemisphere is composed of smaller parts or *lobes*, separated from one another by deep crescentic fissures. These lobes, as well as the vermiform processes, are highly subdivided on their sides and surface, by crescentic furrows, or *sulci*, into numerous parallel, thin *laminæ*, some of which may be traced continuously over the vermiform processes, from one hemisphere to another.

The superficial part of the cerebellum, even of its minutest laminæ, many of which are hidden at the bottom of the principal sulci, consists of grey or cineritious matter, named, as in the cerebrum, the *cortical* substance. It is composed of large multipolar nerve cells, mixed with white fibres, and arranged in thin strata. The interior of the cerebellum consists of *white* or *medullary* substance, which projects into the various lobes, and thence again, in the form of thin plates, into the multitudinous laminæ ; hence a vertical section through the cerebellum, made across its laminæ, presents a beautiful arborescent internal white substance, surrounded by foliated bendings of the grey matter, an appearance which has been named the *arbor vitæ*, or *tree of life*, fig. 59, *d*. Imbedded in the white substance of each hemisphere, is a plicated or folded sac of grey matter, open in the direction of the peduncles of the cerebellum, and having white substance in its interior. Owing to the indented grey line which they present when cut through, these masses of grey matter, are named the *corpora dentata* of the cerebellum. The peduncles of the cerebellum, composed of white fibres, form three sets, as follows :—First, a *superior* pair of *peduncles*, which pass upwards, at the back of the cerebral peduncles, to the corpora quadrigemina and adjacent parts; the white fibres of these peduncles, chiefly issue from the

interior of the corpora dentata. Secondly, a *middle* pair, which cross below, and embrace, the peduncles of the cerebrum, and so form the pons Varolii. Lastly, an *inferior* pair, which pass down to the sides and back of the medulla oblongata, of which they form the so-called restiform bodies, and, by them, are connected with the posterior and lateral columns of the spinal cord. The superior peduncles of the cerebellum, may be said to be composed of *longitudinal commissural* fibres, uniting it to a part of the cerebrum; the middle peduncles form *transverse commissural* fibres, which connect the two cerebellar hemispheres together, and bring them into relation with the grey matter diffused in the substance of the pons Varolii, forming in fact its transverse fibres. Finally, the inferior peduncles are *longitudinal commissural* fibres, connecting the cerebellum with the medulla oblongata and spinal cord. It has been recently stated that all the fibres of the three peduncles of the cerebellum, proceed from, or end in, the interior of the folded sacs of grey matter known as the corpora dentata; and that it is from the outer surface of these sacs, that all the fibres reaching to the laminated grey matter on the surface of the organ, in reality proceed; the fibres of the superior and inferior peduncles are said to decussate within the cerebellum; those of the former, end in a mass of grey matter, in the back part of the cerebral peduncles; those of the latter, in the grey nucleus of the olivary body of the medulla oblongata. (Luys.) These statements require confirmation.

Beneath the superior peduncles, and bounded below by the back of the medulla oblongata, is a space, communicating, by a narrow canal, named the aqueduct of Sylvius, with the third ventricle of the cerebrum, and forming the so-called *fourth ventricle*.

The *Pons Varolii.* This part, already frequently mentioned, is composed superficially of transverse commissural white fibres, which connect the two halves of the cerebellum. But its deeper parts contain, intermixed, however, with other *transverse*, *circular*, or *arciform* fibres, the numerous *longitudinal* fibres which are continued from the base of the cerebrum, and from the cerebellum, to the medulla oblongata. The undermost longitudinal fibres connect the cerebral peduncles with the anterior pyramids of the medulla; whilst the fibres towards the back of the pons, partly serve to connect the cerebrum with the posterior and lateral columns of the medulla, and partly join the cerebellum to the restiform bodies of the latter.

In the interior of the pons is found, moreover, a large quantity of diffused grey matter.

The *medulla oblongata.* The medulla oblongata, fig. 59, *e*, may be regarded as chiefly forming an extension downwards of the peduncles of the cerebrum, and of the inferior peduncles of the cerebellum. Like those parts, it consists of two halves, which, however, are only slightly marked off from each other, in the middle line, in front and behind. In front, is seen a slight median longitudinal fissure, which, moreover, is interrupted by numerous obliquely intersecting bands of white nervous substance. On each side of this fissure, are two narrow columns of white substance, named the *anterior pyramids* ; outside these, are two oval eminences, named the olivary bodies ; external to these, and therefore at the sides of the medulla, are, in succession, the lateral columns, the tubercles of Rolando, the restiform bodies, and at the back, on either side of the middle line, the *posterior pyramids.* At the back of the medulla oblongata, the restiform bodies and the posterior pyramids, are seen to diverge as they are traced upwards ; and the latter bound below an angular space, which is the *floor of the fourth ventricle.* On this floor are seen certain important eminences, two on each side, formed by special accumulations of grey matter, and giving origin to large nerves; certain white transverse streaks, which are the roots of the auditory nerves, are likewise seen ; and, lastly, a pointed depression, directed downwards in the middle line, corresponding with the tip of the so-called *calamus scriptorius*, and leading into a canal in the spinal cord.

The *anterior pyramids* of the medulla oblongata, are composed entirely of white fibres, and are continuous upwards through the pons, with the under part of the peduncles of the cerebrum, and downwards with the anterior and lateral portions, or so-called *columns*, of the spinal cord. Most of the fibres of the anterior pyramids pass obliquely across the median fissure, partly to the anterior, but chiefly to the lateral, columns of the opposite side of the cord, so that the fissure here, is interrupted, as already stated, by intersecting bundles of fibres, which form the so-called *decussation of the pyramids* ; some of these are said to pass down into the posterior part of the spinal cord ; a certain number of the outermost fibres of the pyramids do not decussate, but descend into the anterior columns of the cord on their own side. The *olivary bodies* consist internally, of a folded or plicated sac of grey matter, open towards the

centre of the medulla, and named the *corpus dentatum* of the olivary body; but there are numerous white fibres, within, and around, this ganglionic centre; the external fibres are continued downwards into the antero-lateral columns of the cord, and upwards into the under part of the cerebral peduncle; the fibres which proceed from the interior of the corpus dentatum, ascend to the corpora quadrigemina. The *lateral columns*, also composed of white fibres, descend from the cerebral, and middle cerebellar peduncles, to the sides of the cord, partly undergoing decussation below, and forming a transverse commissure above, behind the corpora quadrigemina. The *restiform bodies* consist of white fibres, including a ganglionic mass of grey matter; they connect the inferior peduncles of the cerebellum with the posterior and lateral columns of the cord. The *posterior pyramids*, composed of white fibres, descend from the upper or back part of the cerebral peduncles, to the posterior part of the lateral, and to the posterior columns of the cord; some of these fibres are said to decussate opposite the back of the pons. Embracing the upper part of the two halves of the medulla oblongata, are certain transverse sets of fibres, superficial and deep, named *arciform fibres*, which serve to connect together, not only the two halves of the medulla, but all its component masses of grey matter; many of these fibres are associated especially with the corpora dentata of the olivary bodies.

The grey matter of the pons, as already stated, is diffused amongst the longitudinal and transverse white fibres; but in the medulla oblongata, it is collected together into more compact and definite masses. Of these, the folded corpus dentatum of the olivary body, has already been described; the tubercle of Rolando encloses a rounded mass, which is continuous below, with the so-called posterior cornu of the grey matter of the spinal cord; the rest of the grey matter of the medulla is chiefly collected in symmetrical masses, situated in its posterior portion, closely contiguous, and more or less blended together; they constitute special ganglionic centres of origin of most important cranial nerves. In the lower part of the medulla oblongata, the grey matter becomes more concentrated, and more covered in behind by the white substance, until, at length, it passes into the completely enclosed grey matter of the cord.

From the preceding account, it will be seen that the medulla oblongata, like the cerebral, and cerebellar peduncles and the

pons, is white externally; but it has grey matter intermixed with all its component parts, except with the white fibres of the anterior pyramids; moreover, the grey matter approaches very closely the posterior surface of the medulla, where it seems, as it were, to have its interior opened out.

The *spinal cord.* The *spinal cord*, fig. 12, *c*, fig. 60, *c*, *c*, a cylindrical mass of nerve substance, forms the prolongation downwards of the medulla oblongata. It presents a shallow, open, anterior median fissure, and a deep close posterior median fissure, which mark it off into a right and left half, united together by a narrow, deep, central commissural part. In each half, are two slight longitudinal lines, serving to distinguish it into what are called the *anterior*, *lateral*, and *posterior columns*, a narrow band of the latter, next to the posterior median fissure, being named the *posterior median column.* Opposite to the lower part of the neck, and again towards its lower end, the spinal cord presents an increase of substance, forming the *cervical* and *lumbar enlargements* of the cord. At its lower end, opposite the first lumbar vertebra, it terminates in a point, which is fixed by a long filament, extending down the spinal canal, to the sacrum. The spinal cord is composed of white substance externally; but on making a transverse section through any part of it, it is seen to contain, within the external white matter, a quantity of grey matter. Quite in the upper part of the cord, this is somewhat diffused; but in the cord generally, it is arranged in the form of two crescents, fig. 61, A, one in each half of the cord, and placed back to back, so that the horns of each crescent advance towards the shallow lateral longitudinal lines seen on the surface of the cord. Again, quite at the lower end of the cord, the grey matter loses its crescentic arrangement, and forms a slight rounded mass; and the white matter, which progressively decreases in quantity from above downwards, at length disappears, and at the extreme point, only grey matter exists. The white matter altogether, forms about seven-eighths, and the grey, one-eighth, of the entire substance of the cord. The anterior horn of each crescent is short and thick; whilst the posterior horn is long and narrow. The posterior horn at its hinder and outer part, is more transparent than elsewhere, forming the so-called *gelatinous* portion, in which the nerve cells are large and multipolar; near the root of this cornu, on its inner side, is another peculiar column of grey matter, named the *vesicular* column. Throughout the whole extent of the cord, the grey

matter of the one side is connected with the grey matter of the other, by what is called the *central grey commissure.* In

Fig. 60.

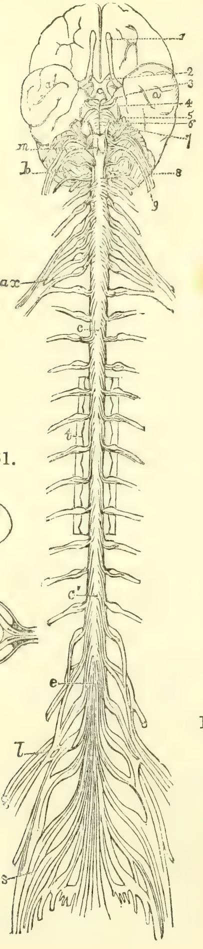


Fig. 60. Under surface or base of the cerebrum, and cerebellum, and of the pons Varolii and medulla oblongata, also the anterior surface of the spinal cord, to show the mode of origin of the cranial nerves from the base of the brain, and that of the spinal nerves from the spinal cord. *a, a,* cerebral hemispheres. *b,* right half of cerebellum. *m,* medulla oblongata; above this, is a transverse white mass, the pons Varolii. *c, c′,* the spinal cord, showing its cervical and lumbar enlargements, and its pointed termination. *e,* the cauda equina, formed by the elongated roots of the lumbar and sacral nerves. 1 to 9, the several cranial nerves, arising from the base of the brain and sides of the medulla oblongata. Below these, on each side, are the roots or origins of the spinal nerves, cervical, dorsal, lumbar, and sacral. In some of these, the double root can be seen, and the swelling or ganglion on the posterior root. *a x,* the axillary or brachial plexus, formed by the four lower cervical and first dorsal spinal nerves. *l,* the lumbar plexus. *s,* the sacral plexus, formed by the last lumbar nerve, and first four sacral nerves. *t,* shows a piece of the sheath of the cord cut open, and, within it, a portion of the ligamentum denticulatum which supports the cord.

Fig. 61.

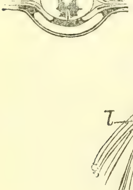


Fig. 61. A, a transverse section through the cord, to show the form of the grey cornua, or horns, in the midst of the white substance. B, shows the same parts; and also the membranes of the cord. and the anterior and posterior roots of a pair of spinal nerves springing from its sides.

the centre of this commissure, is the *central canal* of the spinal cord, a passage measuring about $\frac{1}{100}$th of an inch in diameter, and lined with ciliated columnar epithelium. In front of, and behind, the grey commissure, is a thin layer of white substance, which forms the bottom of the anterior and posterior median fissures. The cervical and lumbar enlargements of the cord, are principally caused by an increase of the grey matter.

Taking a general view of the brain and spinal cord, we see that the cerebrum and cerebellum are composed of grey matter externally, which grey matter, especially in the case of the cerebrum, forms a large proportionate share of its mass. On the other hand, the cerebral and cerebellar peduncles, the pons Varolii, the medulla oblongata, and the spinal cord, are composed of white matter externally, and of grey within. In the interior of the cerebrum and cerebellum, there is chiefly white substance; whilst in the interior of the cerebral and cerebellar peduncles, pons, medulla, and cord, we meet with grey matter. Special grey masses, however, are also found in the lower part of the interior of the cerebral hemispheres, resting upon the diverging and expanding peduncles, viz. the corpora striata, optic thalami, corpora quadrigemina, and corpora geniculata. The cerebellum also has its special internal grey corpora dentata, and so have the olivary bodies of the medulla oblongata. The course of the white fibres in the medulla oblongata and the spinal cord, and their connections with the masses of grey matter within those parts, and with the roots of the nerves, will be hereafter described.

The *cerebro-spinal nerves*. These nerves are divided into two sets, called the *cranial* nerves, and the *spinal* nerves, according as they pass to their respective destinations through openings in the base of the cranium, or through the intervertebral foramina between the several vertebræ.

The *cranial nerves*. These consist of nine pairs. The parts usually defined as the *first* pair, or the *olfactory nerves*, fig. 60, 1, are really extensions of the cerebrum, and should be named the *olfactory lobes*. They are attached to the anterior cerebral lobe by three roots. The true olfactory nerves, or nerves of smell, arise from these lobes; they are very numerous, and pass through minute openings in the ethmoid bone, which forms the roof of the nose; within the upper part of that cavity, they spread out beneath the mucous membrane, and supply

branches which advance to its surface to receive the stimulus of odours.

The *second* pair, the *optic nerves*, 2, or *nerves of sight*, arise on each side, by flat white bands, named the *optic tracts*, the fibres of which may be traced from the optic thalami, corpora quadrigemina, and corpora geniculata, and, it is said, even from the occipital lobes of the cerebral hemispheres. These tracts pass forward on the sides of, and beneath, the cerebral peduncles, and meet in front, as already mentioned, at the *optic commissure*; from this, the optic nerves proper are given off in front, and pass through the optic foramina in the sphenoid bone, to enter the bottom of the orbits, whence they proceed forwards to the back of the eyeballs. There, each nerve piercing the thick coats of the eyeball, spreads out in its interior to form the *retina*, which receives the stimulating impressions of light. At the optic commissure, a portion of the fibres of the optic tract continue into the corresponding optic nerve; another portion passes over into the optic nerve of the opposite side, thus forming a partial *decussation*; certain transverse fibres pass from one optic *tract* to the other, doubtless running back to the brain on each side; whilst other transverse fibres pass from one optic *nerve* to the other, serving to associate the retinæ of the two eyes; these are not directly continuous with the fibres of the optic tracts.

The *third* pair, *motores oculi*, or *motor nerves of the eyeball*, 3, arise from the inner surface of the cerebral peduncles, having deep origins from the grey matter there; a few fibres also spring from the corresponding corpora quadrigemina. They enter the orbit, and supply all the muscles of the eyeball, except the superior oblique and the external rectus. This nerve also sends branches, called ciliary nerves, which penetrate the coats of the eyeball, and supply the ciliary muscle, as well as the circular fibres of the iris.

The *fourth* pair, or *pathetic nerves*, 4, the smallest of the cranial nerves, arise from the back of the cerebral peduncles, and passing forwards, outside the peduncles, a little below the corpora quadrigemina, enter the orbit, and supply a single muscle of the eyeball, viz. the superior oblique or trochlear muscle; hence it is also called the *trochlear* nerve.

The *fifth* pair, 5, named the *trigeminal* nerves, because they divide into three chief branches, and *trifacial*, because these three branches appear on the face, are the largest of the cranial nerves. They arise from the sides of the pons Varolii, by *two*

distinct *roots*, viz. a larger, softer root, which enters a crescentic ganglion, called the *Gasserian ganglion*, from which the three great divisions or branches of the nerve are given off; and a smaller and firmer root, which passes beneath the ganglion, and joins the third division only of the nerve. Both the roots of the fifth nerve, arise from the grey matter in the pons and medulla oblongata. Of the three divisions or branches, the *first* or smallest, the *ophthalmic*, enters the orbit, and there supplies the eyeball and all its appendages; it gives branches likewise to the mucous membrane of the nose and the adjacent sinuses, and finally supplies the skin upon the crown of the head, the forehead, and the root and point of the nose, fig. 62. The *second* division, or *superior maxillary*, supplies branches to the lining membrane of the nose, and Eustachian tube, to the sinus in the upper jawbone, to the palate, to the upper teeth and gums, and to the skin upon the side of the nose, the cheek, and upper lip. The *third*, or largest division, the *inferior maxillary*, supplies branches to the muscles of mastication, an important branch to the anterior two-thirds of the tongue, named the *gustatory nerve*, or nerve of taste, common sensory branches to the lower teeth and gums, the floor of the mouth, and the skin of the external ear, temple, lower part of the cheek and face, lower lip, and chin; and, lastly, branches to a few neighbouring muscles, and to the parotid gland. All three of the divisions of this large nerve, give off sensory branches; but only the third division supplies motor branches. The three divisions of the fifth nerve, are connected by some or other of their smaller branches, with certain ganglia of the sympathetic nerve, and also with the facial nerve.

The *sixth* pair, or *abducent nerves*, *abducentes oculorum*, 6, arise from between the pons and the medulla oblongata, receiving fibres from both these parts. They supply a single muscle of the eyeball, viz. the external rectus, which abducts the eye; hence the special name of these nerves.

The *seventh* pair of cranial nerves, 7, consist, on each side, of *two portions*, one soft, destitute of a firm neurilemma, named the *portio mollis*, the other harder and round, named the *portio dura*; these are distinctly different nerves. The *portio mollis* is the *auditory nerve*, or nerve of hearing; it arises at the back of the medulla oblongata, from the floor of the fourth ventricle, and coursing forward, immediately behind the pons, passes from the cranial cavity into an opening in the petrous portion of the temporal bone, named the internal auditory meatus or

canal, at the bottom of which it pierces the bone by minute openings, and is then distributed to the complicated chambers of the internal ear. The *portio dura* arises also from the medulla oblongata, passes, with the portio mollis, into the internal auditory meatus, and there communicates with it; but it then leaves that nerve, and escapes by a special opening, the stylo-mastoid foramen, through the base of the skull, and emerges close to the inner side of the mastoid process. As it passes through the temporal bone, it presents a gangliform swelling which is connected with two neighbouring sympathetic cranial ganglia. It next descends outwards, behind the border of the lower jaw, running through and supplying the parotid gland, and then dividing into numerous branches (see fig. 62), like the foot of a bird, hence named *pes anserinus* or goose's foot, ramifies over the face, and supplies all the facial muscles. It also supplies, partly, the muscles of the outer ear, and likewise one little muscle of the tympanum or middle ear, and gives off a remarkable branch, named the *chorda tympani*, which descends to the submaxillary salivary gland, and joins the gustatory nerve.

The *eighth* pair of nerves, 8, placed along the side of the medulla oblongata, consist of *three* portions, which are all given off from the grey matter within the posterior part of the medulla oblongata and spinal cord. The *first*, called the *glosso-pharyngeal* nerve, is the smallest and highest; it passes out through the base of the skull into the neck, and supplies chiefly, as its name implies, the mucous membrane of the tongue, and the lining membrane, and partly the muscles, of the pharynx; but it also sends branches to the tonsils, the palate and its muscles, and the Eustachian tube, and even to the tympanum or middle ear. The *second* or largest portion of the *eighth* pair, named the *pneumogastric nerve*, *par vagum*, or *vagus nerve*, leaves the sides of the medulla oblongata, passes through the base of the skull into the neck, and is distributed chiefly, as its first name indicates, to the lungs and stomach. It is called vagus, or the wandering nerve, from the great distance from the head, to which its branches extend. Besides the stomach and lungs, it moreover supplies branches to the muscles and lining membrane of the pharynx, to the lining membrane and muscles of the larynx, the lining membrane and muscular fibres of the windpipe, the mucous and muscular coats of the œsophagus, and, lastly, a most important portion of the nerve, cardiac branches, which go to the heart. The *third*

division of the *eighth* pair, named the *spinal accessory* nerve, arises, by many funiculi, from the lateral columns of the spinal cord, low down in the neck, and therefore, from its origin, might be deemed a *spinal* nerve ; but it ascends through the foramen magnum into the skull, receives additional roots from the sides of the medulla oblongata, and then passes out through the base of the skull, into the neck ; here it communicates with the pneumogastric nerve, and then descends obliquely downwards, and supplies chiefly the sternomastoid, and trapezius muscles. The glosso-pharyngeal and pneumogastric nerves, have each ganglionic masses upon their trunks ; the spinal accessory nerve has no such ganglion. The *ninth* pair of cranial nerves, 9, or *hypo-glossal* nerves, emerge from the front of the medulla oblongata, between the olivary body and the anterior pyramid, though their fibres arise deeply from grey matter at the back part of the medulla. The nerves pass forwards, out of the cranium, through special foramina in the occipital bone, and, entering the neck, run onwards, to be distributed chiefly to the muscles of the tongue. They also supply, however, most of the muscles in front of the neck. In some mammalia, this nerve has a small posterior sensory root, having a ganglion upon it, thus manifesting an affinity with the spinal nerves, next in succession to it, which we have immediately to describe.

Estimates have been made of the number of nerve fibres present in several of the cranial nerves. The numbers in the following nerves, which, as we shall hereafter see, are motor in function, are as follows—the third or oculo-motor, 15,000 ; the fourth or pathetic, 1,100 ; the small root of the fifth, 9,000 to 10,000 ; the sixth or abducent nerve, 2,000 to 2,500 ; the portio dura or facial, 4,000 to 4,500 ; the spinal accessory, 2,000 to 2,500 ; and the ninth or hypo-glossal, 4,500 to 5,000. Of the other nerves, the glosso-pharyngeal is said to contain 3,500, and the pneumo-gastric 4,000 small and 5,000 larger nerve fibres.

The *spinal nerves.* The spinal nerves, arising from the spinal cord, consist of thirty-one pairs, fig. 60, arranged into five groups, named, according to the vertebræ, between which they pass out from the spinal canal, the *cervical*, *dorsal*, *lumbar*, *sacral*, and *coccygeal* nerves. There are eight pairs of cervical nerves, twelve dorsal, five lumbar, five sacral, and one, sometimes two, coccygeal.

Each spinal nerve arises from the corresponding side of the

spinal cord, by means of *two roots*, which consist of bundles, or funiculi, springing from the lateral furrows upon the cord. The deep paths of these roots within the cord, require to be carefully studied.

The funiculi which form the *posterior root*, larger and more numerous than those of the anterior root, arise from the posterior lateral furrow. Within the cord, they may be traced into, or through, the posterior white columns, whence they proceed either downwards, transversely, or upwards, forming three sets. The descending set pass obliquely downwards, through the grey matter, and even reach the anterior horn, whence they penetrate the anterior white columns, spreading upwards and downwards, many of them entering the anterior roots of the neighbouring nerves, but some losing themselves in the anterior columns. The transverse set of fibres enter the posterior horn, crossing the gelatinous portion of this; some join the multipolar cells, others pass between them, either into the posterior or lateral columns; others cross through the transverse commissure of the cord, to reach the posterior and lateral columns of the opposite side, some being traceable, it is said, to the roots of the nerves; lastly, some end in a network reaching towards the anterior cornua. The ascending set are partly continuous with the fibres of the posterior columns, but most of them pass obliquely upwards through these columns, and enter the grey substance, where some appear to form loops, and return into the posterior columns.

The fibres of origin of the *anterior roots*, pass in distinct horizontal bundles, through the anterior columns, to the anterior horn of grey matter; thence they diverge in three directions, upwards, downwards, and horizontally. Many may be traced to the large multipolar cells of the anterior horn; some pass through into the anterior, and others into the lateral, white columns of the same side; others proceed through the anterior part of the commissure, and pass over to the opposite side, into the anterior and lateral columns, and, it is said by some, even into the anterior roots of that side; many enter deeply into the cornua, and then diverge upwards, downwards, and inwards; the latter come into near proximity with the fibres of the posterior roots, and possibly pass into them.

On leaving the cord, the posterior funiculi are gathered into a single nerve root, upon which is found an oval mass of grey matter, situated usually in the intervertebral foramen, and called

a *spinal ganglion*, or *ganglion* of the *posterior root* of a spinal nerve. The anterior funiculi, smaller and less regularly disposed, emerge in a similar manner from the anterior lateral furrow. The *anterior root*, formed by the gathering together of these funiculi, passes *over*, and *beyond*, the spinal ganglion of the posterior root, and then joins that root to form a single *trunk*, which, passing out from the intervertebral foramen at the side of the vertebral column, divides into anterior and posterior *branches*, which are distributed, the latter to the muscles and skin behind the spine, and the former to the muscles and integuments of the parts of the body in front of the spine, and to the limbs; the anterior branches are accordingly generally larger; moreover, they form *plexuses*, as will be presently mentioned, and they are all connected by branches with the sympathetic nerve.

The upper *cervical* nerves supply the deep and posterior muscles, and the skin, of the neck and shoulder. From the anterior branches of the third and fourth cervical nerves, with a small fasciculus from the fifth, a most remarkable branch, called the *phrenic nerve*, runs down through the thorax, on the sides of the pericardium, and reaches the diaphragm, or partition between the thorax and abdomen, to the muscular fibres of which it is distributed. The lower cervical nerves, which arise from the cervical enlargement of the cord, and are much larger than the upper cervical, are chiefly distributed by the large anterior branches, to the muscles, the skin, and other parts of the upper limbs, a few branches being furnished to the neck and trunk. The *dorsal* nerves give off, besides some small branches to the upper limb, the *intercostal* nerves, which supply the proper muscles of the thorax, namely, the intercostal muscles, the deep muscles of the back, the upper part of the muscles of the abdomen, and the skin over the corresponding parts of the trunk. The first dorsal nerve assists in supplying the upper limb. The *lumbar* nerves supply the lower part of the muscles of the back and abdomen, the muscles within the pelvis, and the muscles and skin of the lower part of the trunk, of the upper part of the thigh, and the skin of the inner side of the thigh and leg, down to the heel. The first lumbar nerve is sometimes joined by a branch from the last dorsal, whilst the fourth partly, and the fifth almost wholly, descends to join the large upper sacral nerves. The *sacral* nerves chiefly supply certain muscles of the pelvis, those of the back of the thigh, all those of the leg and foot, and the parts of the skin of the lower limb, not sup-

plied from the nerve already mentioned. The two lower lumbar, and the three upper sacral, nerves arise from the lumbar enlargement, and are the largest of the spinal nerves, and indeed larger than any of the cranial nerves, being the largest nerves in the body. The *coccygeal nerves*, the smallest of the entire series, supply the parts adjacent to the coccyx.

The *roots* of the cervical nerves within the spinal canal, are short, arise at brief intervals from the sides of the cord, and pursue a nearly horizontal course to the interspaces, or places of exit, between the vertebræ; but, in the dorsal region, the roots of the spinal nerves are longer and more oblique; and, on arriving at the lumbar and sacral nerves, as the spinal cord itself terminates opposite the lower border of the first lumbar vertebra, the roots of the nerves spring in a crowded manner from the cord, and, descending in the vertebral canal, enclosed within the sheath of the cord, pursue a progressively longer and more vertical course, before they reach their respective intervertebral foramina of exit. The pointed lower portion of the spinal cord, together with the roots of the lumbar and sacral nerves descending from it, produces the appearance named the *cauda equina*, or horse's tail, fig. 60, *e*.

On comparing the preceding description of the cranial with the spinal nerves, it will be noticed that all the spinal nerves arise by *two roots*, viz. a posterior ganglion-bearing root, and an anterior root having no ganglion, and joining the other root beyond its ganglion. Of the cranial nerves, however, the fifth nerve alone so far resembles a spinal nerve as to have a double root, one ganglionated and the other not; whilst the glosso-pharyngeal and pneumogastric nerves have ganglia upon their trunks, and the remainder arise by single roots unprovided with ganglia. We shall hereafter return to the subject of the homology of the cranial with the spinal nerves.

Nervous plexuses. In pursuing their course to the various tissues which they supply, the branches of the nerves, both cranial and spinal, always continue to divide and subdivide into smaller and smaller twigs, until they arrive at minute filaments, or even at single fibres, which terminate in various ways, in the tissues to which they are distributed (p. 56). At some parts of their course, certain branches of the nerves reunite again, so as to form angular *networks*, or meshes, called *plexuses*. Examples of these plexuses, are met with in certain junctions, or anastomoses, of the fifth and facial nerves on the

face, and in the union of the pharyngeal branches of the glosso-pharyngeal and pneumogastric nerves. Smaller meshes of anastomosis, or junctions, occur in the branches of the same nerve, as in those of the olfactory nerves beneath the nasal mucous membrane, and in the still more microscopic interweaving of the fibres of the optic nerve in the retina, and of the auditory nerve in certain parts of the internal ear. But very large and remarkable plexuses are formed by the anterior branches of the spinal nerves. Thus, the *cervical plexuses* are formed between the first four cervical nerves, at each side of the neck; the so-called *brachial* or *axillary plexuses*, fig. 60, *ax*, are composed of branches of the four lower cervical and first dorsal nerve, at the root of the neck, and give off the large nerves of the upper limb, fig. 62; the *lumbar plexuses*, fig. 60, *l*, are formed by the four upper lumbar nerves; and, finally, the *great sacral plexuses*, *s*, are formed by the last two lumbar and four upper sacral nerves, from which the very large nerves of the lower limb proceed, amongst them the great *sciatic nerve*, the largest nerve in the body. In these plexuses, there is an interchange not only of the funiculi or bundles of nerve fibres, but necessarily of the nerve fibres themselves, belonging to various cranial or spinal nerves. The nerve fibres may pass, from one nerve entering the plexus, into all the nerves given off from it, and this in various degrees of intermixture; these fibres themselves, however, never divide and unite, but retain their continuity from the brain, or cord, to the localities of their ultimate distribution. The effect of these plexuses is, that any given nerve beyond the plexus, contains, or is composed of, nerve fibres springing from a considerable length of the spinal cord, and thus their purpose seems to be—*first*, to establish a connection between any one point of local distribution and a large extent of the nervous centres; and, *secondly*, to connect many points of local distribution with some given portion of the nervous centres. Thus, muscles supplied through such a plexus, are brought into physiological relation with various portions of the cord. In the same manner, nerve fibres having different endowments, sensory, motor, or reflex, are hereby intermixed; and, moreover, fibres possessing the same endowments, are more widely distributed.

The Sympathetic Nervous System.

The *sympathetic nervous system* consists of two knotted *ganglionated nervous cords*, which are placed one on each side of the vertebral column, in the neck, in the thorax, in the abdomen, and in the pelvis, fig. 62. These cords are connected with certain other ganglia situated deeply between the bones of the cranium and the face, and also with certain important interlacements, or *sympathetic plexuses*, and ganglia, placed on, or near, the great viscera in the chest and abdomen, and named the *prevertebral sympathetic plexuses.* By many authorities, the ganglia connected with the trunks or roots of certain cranial nerves, and those situated upon the posterior roots of the spinal nerves, are regarded as belonging to the sympathetic system.

The *ganglia* of the sympathetic are fewest and largest in the neck, there being only three, instead of a number equal to that of the cervical nerves: perhaps a process of fusion here takes place. The *superior cervical* ganglion measures at least $1\frac{1}{4}$ inch in length; there are also a middle and lower cervical ganglion, the former being sometimes absent. The *dorsal* ganglia are more regular, being usually twelve in number, and of more moderate size. The *lumbar* and *sacral* ganglia become still smaller, and lie in front of the bodies of the vertebræ, instead of at the sides. Lastly, the ganglionated cords of the two sides, terminate below in a single coccygeal ganglion, placed on the front of the coccyx. Each of these ganglia, from the neck to the pelvis, is connected with the adjacent spinal nerve, as those in the cranium and face are with the cranial nerves, by one, or generally two, short nervous cords proceeding outwards; besides this, each is, of course, connected with the ganglia above and below it, by the main trunk of the sympathetic itself; finally, each gives off a branch inwards to the so-called *prevertebral* plexuses.

From the superior cervical ganglion of the sympathetic, branches ascend to the base of the skull, and form direct, or indirect, communications with certain cranial nerves; as, for example, with the third, sixth, facial or portio dura of the seventh, and particularly with the fifth nerves. It is with these branches, also, that the small sympathetic ganglia, found in the spaces between the cranial and facial bones, are connected,

Fig. 62.

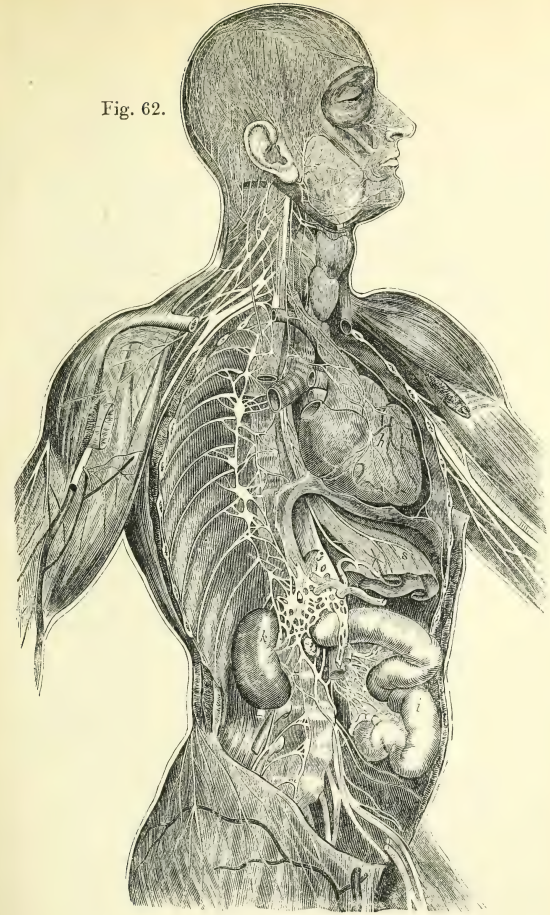


Fig. 62. The nerves. On the face and head, are branches of the facial, trigeminal, and cervical nerves. In the neck, are the cervical and brachial plexuses and nerves. In the thorax, abdomen, and pelvis, is seen the right sympathetic nerve, consisting of a ganglionated cord connected with the intercostal nerves, and giving off branches in front, to the prevertebral plexuses, which supply the viscera, e. g. the heart, *h*, the stomach, *s*, the intestines, *i*, and the kidney, *k*, near which is seen the solar plexus. The lumbar plexus is seen in the pelvis.

viz. the *lenticular* ganglion in the orbit, the *otic* ganglion and the *spheno-palatine* ganglion behind the nasal cavities, and the *submaxillary* ganglion situated on the submaxillary salivary gland; all four ganglia are connected with branches of the fifth cranial nerve.

Of the prevertebral plexuses of the sympathetic, the chief are the *cardiac*, the *solar*, and the *hypogastric*; but there are several secondary plexuses, such as the *laryngeal*, *pharyngeal*, the *pulmonary*, the *renal*, and others. The cardiac plexus is derived from the descending cardiac branches of the cervical sympathetic ganglion, mixed with branches of the pneumogastric; the great solar plexus is situated in the abdomen, in front of the aorta, and is derived from the three *splanchnic* nerves proceeding from the lower six thoracic ganglia, and from branches given off from the grey matter of a large sympathetic ganglion, named the *solar ganglion*; it is joined also by a few terminal branches of the pneumogastric nerves. The renal plexuses are derived partly from the solar plexus, and partly from the lowest splanchnic nerves; and lower down, are the hypogastric plexuses and their off-sets.

The branches proceeding from the various sympathetic ganglia and plexuses, are thus distributed. The *lenticular* ganglion receives fibres from the third, sixth, and fifth cranial nerves, and supplies branches to the eyeball, especially destined for the iris, and for the bloodvessels, including those of the ciliary processes. The *otic* ganglion, connected with the fifth and glosso-pharyngeal nerves, gives branches to a muscle in the tympanum or middle ear, and thus probably assists in the control of parts of the organ of hearing. The *spheno-palatine* ganglion is connected with branches of the fifth and the facial nerves; its branches may be traced to the mucous membrane of the nose and palate, so that it may be considered as associated with the parts concerned in the functions of taste and smell. The *submaxillary* ganglion, which communicates with the fifth and facial nerves, sends its branches chiefly to the submaxillary gland. The Gasserian ganglion on the root of the fifth pair, also the ganglia on the trunks of the glosso-pharyngeal and pneumogastric nerves, and, lastly, those found on the posterior roots of the spinal nerves, if these be really sympathetic ganglia, as seems probable, must supply sympathetic nerve fibres, which are blended with the fibres of the nerves on which they are respectively placed,

and are most likely distributed with them to various parts of the body.

Of the chief plexuses, the cardiac sends branches to the heart, fig. 60, *h*, and to the great bloodvessels, and from these, others are continued on to the roots of the lungs, assisting in the formation of the pulmonary plexuses. From the aorta, the sympathetic nerves are continued on to the great arteries, and so on to all the arteries of every part of the body. From the solar plexus, proceed the branches to the stomach, *s*, intestines, *i*, liver, kidneys, *k*, and other abdominal viscera; each organ having a secondary plexus named accordingly. The hypogastric plexus supplies the pelvic viscera and their bloodvessels.

The ganglia of the sympathetic nerve are its proper centres: they consist of coloured nerve cells, mostly, it is said, unipolar, or provided with only one process; they give origin to the proper sympathetic nerve fibres, which are nearly all of the gelatinous, or non-medullated, kind (p. 55). But the cords which connect the trunks of the sympathetic with the several cranial and spinal nerves, are whitish in colour, whiter even than the branches given off from the sympathetic to its plexuses; whilst the ultimate ramifications on the arteries, are of a pale pinkish hue. These last ramifications, which, as just mentioned, are commonly supported upon the small arteries of the different parts towards which they run, are composed of a few tubular fibres, mixed with many of the non-medullated kind. They are often connected with, and reinforced by, numerous additional minute ganglia: this is especially the case in regard to the arteries of the viscera. In the limbs, sympathetic nerve fibres are probably blended with the cerebro-spinal nerves. The final destination of the sympathetic nerve fibres, whether medullated or non-medullated, is not well known; but it is supposed that they end, in part at least, in the muscular coat of the small arteries. Even in the substance of certain organs, as, for example, in the heart and lung, innumerable minute visceral sympathetic ganglia are met with; and beneath the mucous membrane of the alimentary canal, microscopic structures, resembling grey nerve cells, are also found, and are supposed to belong to the sympathetic system.

On examining the course of the fibres forming the connecting cords between the trunk of the sympathetic and the cranial and spinal nerves, which are sometimes regarded as

the *roots* of the sympathetic system, it is found that they consist of two sets of fibres, passing each from one system to the other: the cerebro-spinal white medullated fibres pass through the ganglia of the sympathetic, and so onwards into the longitudinal cords which form the trunks of the sympathetic nerve, and thence into the branches given off to the prevertebral plexuses; the proper sympathetic fibres, always small and usually non-medullated, pass to the anterior branches of the corresponding spinal nerve. The posterior roots receive fibres from their own spinal ganglion. From these facts, it follows that the fibres of the cerebro-spinal and sympathetic systems are here intermingled; it is also apparent why the branches of the sympathetic nerves, although more or less white in the first part of their course, become more pinkish as they get nearer to their distribution. As all the sympathetic nerves probably contain a few fibres derived from the cerebro-spinal axis, so all the cranial and spinal nerves probably contain, in their branches of distribution, some sympathetic nervous fibres. It must further be concluded that the sympathetic nervous system is not to be regarded as a mere off-set from the cerebro-spinal system, nor yet entirely independent of it; but rather that it is a *special* nervous apparatus, having numerous grey nervous centres of its own, though intimately connected with, and therefore influenced by, the cerebro-spinal system.

FUNCTIONS OF DIFFERENT PARTS OF THE NERVOUS SYSTEM.

The nerves, whether cerebro-spinal or sympathetic, being composed entirely of nerve fibres, either white or gelatinous, are considered to act merely as *conductors* of impressions, or of the effects of impressions. The white parts of the substance of the spinal cord, the medulla oblongata, the pons Varolii, the cerebral peduncles and hemispheres, and the cerebellum, must also likewise be limited functionally, to conducting properties. The grey matter of the sympathetic ganglia, and of the several parts of the cerebro-spinal axis, must not only conduct, but also reflect, diffuse, and transfer impressions, and must even originate changes which stimulate the excitability of the nerve fibres. The ganglionic masses, whether of the cerebro-spinal or sympathetic system, are therefore said to be *centres of activity*. The connections of the grey matter,

and its greater relative vascularity, are conditions which also favour this view. For the continued activity of both the white and grey matter, it is necessary that they should be adequately supplied with healthy arterial blood, and be maintained within the limits of a certain range of temperature. Imperfectly oxygenated, or imperfectly decarbonised blood, or blood impaired or impoverished, or poisoned by the natural secretions of the body, or by foreign substances introduced into it, is unfit for the healthy nutrition of all parts of the nervous system, and more or less interferes with, or may altogether arrest, their functions. The temperature at which the nervous system can act properly, differs in the warm and cold-blooded animals; it is presumable that, in all cases, the natural temperature of the blood of the animal, is that best fitted for the functional activity of its nervous system. A warm-blooded animal, it has been shown, cannot long survive at a temperature lower than 72°, nor yet above 120°. The benumbing effects of cold on our sensations, and its ultimate fatal results, are well known, and will be hereafter explained.

Functions of the Cerebro-spinal Nerves.

That the nerves are concerned in the functions of sensation and motion, is suggested by the facts, that they are very numerous in all highly sensitive parts, such as the eye, the tongue, and the cutis, or true skin, and are also abundant in the muscles, that they are few in number in the slightly sensitive and non-contractile tissues, such as the ligaments, tendons, and bones, the latter of which have been said to be absolutely insensible in health, and, lastly, that they are entirely absent in the insensible tissues such as cartilage, the cuticle, and the nails. The results of accidental destruction or division of a nerve in the human body, and of its section in experiments upon living animals, afford direct proof of the function of these parts; for when a nerve, the branches of which are distributed to a sensitive part, such as the eye or a portion of the hand, is destroyed by disease, or divided by injury, or in an experiment, the sensibility, general or special, of that part is destroyed; and so also, when a nerve proceeding to certain muscles, is cut accidentally or intentionally, those muscles are paralysed. If in a frog, the bone and all the soft parts of the thigh, with the exception of the nerves, be cut through, sensibility and power of motion are still manifested, in various ways, in the parts so

partially isolated from the body; but, on the other hand, if the nerves themselves be divided, the other tissues remaining uncut, sensibility and motion are destroyed in the parts previously supplied by the cut nerves. Tight ligature of the nerves produces the same loss of sensation and power of movement in the parts below the seat of ligature. There can be no doubt, therefore, that the nerves are concerned in the production of the phenomena of sensation and motion.

If the upper part or end of a divided spinal nerve, which is still in connection with the cord and brain, be pinched or irritated in any way, a sensation, that of pain, is produced; again, if the lower portion, which is severed from the spinal cord, be pinched or irritated, no sensation is felt, but the muscles supplied by the nerve undergo contraction. In these experiments, it is inferred that the upper part of the nerve, being stimulated, conducts the effects of that impression up to the nervous centres, and that the lower part of the nerve conducts those effects downwards to the muscle. Hence the special office which the nerves perform in the phenomena of sensation and motion, is said to be that of acting as conductors. Certain structural arrangements in the nerves and the nerve fibres, have been supposed to favour and render more precise this conducting power, by insulating the channels of conduction; thus, the axis fibre being supposed to be the conducting substance, the medullary sheath and the tubular envelope of the white fibres, are said to act as insulators. In the nerves, the sheath or neurilemma may serve as an additional insulating as well as a protecting investment. No matter how close to the spinal cord the nerves are cut, similar results to those just mentioned ensue, the portion of the nerve detached from the cord never being capable of producing any sensory phenomenon, nor yet being able, if left unirritated, to determine any regular movement in the muscles with which it is still connected. Hence we arrive at the negative conclusion, that the nerves of themselves are not either seats of sensation, or natural centres of origin of motorial stimulus. It has already been stated that the fibres of a spinal nerve, which convey the sensory impressions upwards, are called the *afferent* nerve fibres; whilst those which conduct the effects of motorial stimuli downwards, are named *efferent* fibres.

In the trunks of all spinal nerves, these two kinds of fibres are intermixed; but at the roots of the nerves, it has been discovered, as the result of experiment, that these two kinds of fibres are separated; and that, whilst the afferent or sensory

fibres pass entirely through the posterior ganglion-bearing root up to the cord, the efferent or motor fibres pass from the cord exclusively through the anterior roots. This remarkable natural separation or analysis of the two sets of fibres, was discovered by our countryman, Sir Charles Bell, and forms the basis of his, and of still later, discoveries in the functions of the nervous system.* The doctrine of Sir Charles Bell is demonstrated by the following experiments. If the anterior root only of a spinal nerve be cut across, sensation in the parts below remains unaltered, but the muscles are paralysed, or the power of movement is lost. If the posterior sensory root only be divided, sensation is lost in the parts below, but voluntary power remains. If both roots are divided, sensation and motion are both destroyed. Again, if the lower or distal portion of the divided posterior root be irritated, no signs of pain or other sensation, and no motions, take place in the parts below; but if the upper or proximal end be irritated, evidences of pain ensue; whereas, if the distal portion of the divided anterior root be irritated, movements occur in the muscles below, without manifestations of sensation; but if the proximal portion be irritated, no movements in those muscles take place. Sometimes, however, irritation of the distal cut portion of the anterior roots, produces slight evidences of pain, formerly spoken of as the result of *recurrent sensibility*, and referred to the existence of a few recurrent afferent fibres which pass from the anterior root upwards along the posterior root to the cord. The pain which follows irritation of the distal cut end of the anterior root, has also been attributed to the excited cramps or movements being themselves the cause of pain, by inducing irritation in the sensory fibres of the

* Experiments made on the various parts of the nervous system in living animals, have led to the formation of the most important inferences as to the respective uses of these parts, whether composed of white or grey nervous matter. Sections of various kinds, and stimulation before or after such sections, have, indeed, been the chief methods employed in the investigation of the intricate problems of nervous action. Very numerous instances will have to be mentioned in the following pages. Whilst we may designate, as cruel and profitless, the mere repetition of well-known experiments upon living animals, with the exception of a few of fundamental importance, we must seriously maintain the right of the physiologist to employ, and the propriety of employing, the lower animals in well-considered experiments for the elucidation of those laws of life, which our intelligence prompts us to explore, and on a knowledge of which the alleviation of human suffering so largely depend.

muscles. Certain slight movements produced by irritation of the posterior roots are due to reflex action.

Additional evidence of the properties of the two roots, is furnished by an experiment in which the anterior roots of the three spinal nerves which supply the hind leg of a frog, are divided on the left side; whilst the posterior roots of the corresponding nerves, are divided on the right side. On then pinching or cutting the left leg, or even *cutting it through*, evidence of pain is given by the frog, in energetic motions of every part of the body, excepting those of the limb itself; whereas, if the right leg be pinched or cut, or even *cut through*, no evidence of pain follows, and no decided motion, excepting the twitching of the muscles that happen to be divided. From these and the preceding experiments, it becomes evident that the posterior roots of the spinal nerves, contain the afferent fibres, and convey the effects of sensory impressions inwards to the cord; whilst the anterior roots contain efferent fibres, and convey the effects of motorial stimuli to the muscles. In the trunks and principal branches of the nerves, both sets of fibres are usually intermixed. Hence, if a mixed nerve be ligatured at two points, irritation between the ligatures produces no effect; but if the lower ligature be relaxed, such irritation produces movements in the muscles to which the branches of the nerve are distributed; whilst, if the upper ligature be loosened, pain ensues on like irritation. In the purely sensory branches of the mixed cranial or spinal nerves, as, for example, in those distributed to the mucous membrane of the tongue, and to the skin of the tips of the fingers, only afferent fibres exist; whilst in the proper muscular branches, the fibres are chiefly efferent, though doubtless a few afferent fibres are intermingled, for the purpose of conveying upwards to the nervous centres, the effects of the special sensory impressions produced by the condition of the muscle itself. It is through the spinal nerves that the contraction of the muscles of the trunk and limbs is excited; by them also, those muscles are endowed with their special, though slight, sensibility, are able to produce the muscular sense, the feelings of fatigue or cramp, and to transmit impressions by which we recognise resistance or weight. The spinal nerves likewise are the channels of sensation for the skin and other soft parts of the trunk, limbs, and back-part of the head.

The functions of particular nerves are determined, partly by their ultimate distribution, but also by experiments on

animals, and observations made in cases of injury or disease in man. In this way, the properties of the several cranial nerves have been determined, and the nerves themselves have been classified accordingly. Thus, the olfactory, the optic, and the portio mollis of the seventh pair, or auditory nerve, are purely and specially sensory, and contain afferent fibres only; the third pair, oculo-motor, or motor nerves of the eye, the fourth pair, trochlear, or pathetic nerves, the sixth pair, or abducent nerves, the portio dura of the seventh pair, or facial nerve of each side, and the ninth pair, or hypoglossal nerves, are purely motor nerves, and contain efferent fibres only; whilst, lastly, the fifth pair and the eighth pair, its three divisions being considered as one nerve, are, like the spinal nerves, mixed sensory and motor. The fifth nerve arises, indeed, as we have seen, like the spinal nerves, by two roots, of which the larger one is sensory, partly serving for common sensation, and partly, it is believed, for the gustatory sense, whilst the smaller one is motor. The glosso-pharyngeal division of the eighth pair is sensory, partly tactile, and partly gustatory; the spinal accessory division is chiefly motor, containing a few sensory fibres derived from the pneumogastric, whilst the great pneumogastric itself is partly motor, and partly sensory, some of its terminal branches being sensory, and others motor.

The following table shows briefly these relations :—

CRANIAL NERVES.

First Group.—Sensory . .	First, or olfactory. Second, or optic. Auditory (portio mollis of seventh).
Second Group.—Motor . .	Third nerve (motor of eye). Fourth nerve (pathetic). Sixth nerve (abducent). Facial (portio dura of seventh). Ninth nerve (hypoglossal).
Third Group.—Mixed Nerves	Fifth nerve (trigeminal). Eighth nerve (including its three divisions).

The *special* functions of these nerves are as follows :—The *olfactory*, *optic*, and *auditory* nerves appear to have special endowments, or to react only under the effects of peculiar stimuli, producing odorous, luminous, or sonorous impressions; for no other sensations can be produced by their

irritation. Thus, pinching, or the electric stimulus, does not cause pain, but the sensation of light or noise, if applied to the optic or auditory nerves. Pain may, however, be produced by an excess of their proper stimuli, as by intense light and very loud noise. Their division destroys the function of the sensory organs to which they are distributed. It has not been proved that an ordinary stimulus, applied to the olfactory nerves, produces smell. Further details on these subjects will be given in the Chapter on the Senses.

The third cranial or *oculo-motor* nerve, governs all the muscles of the eyeball, except the external rectus and the superior oblique muscle; through its connection with the lenticular ganglion, it effects the contraction of the pupil, exciting the circular fibres of the iris. This result also follows experimental irritation of the nerve, whilst its division causes dilatation of the pupil by paralysing its circular fibres. It may act as a voluntary nerve, or in the so-called reflex manner, being then excited through the optic nerve. It contains a few sensory fibres, probably derived from communications with the fifth cranial nerve.

The fourth or *pathetic* nerve supplies the superior oblique or trochlear muscle of the eyeball, with motor fibres, which may act voluntarily, or in a reflex manner; it also contains a few sensory fibres.

The fifth or *trigeminal* nerve is a mixed nerve, through which all the parts mentioned in the description of its branches (pp. 314–15) are endowed with sensibility, and through which the movements of the muscles of mastication are effected. Division of this nerve on both sides, within the cranium of a rabbit, destroys the sensibility and mobility of these parts; and the head is carried as if it were a foreign body. Division on one side, paralyses the same parts on one side only. Moreover, in a short time, the cornea becomes opaque, or even ulcerated, and the humours escape. These results have been referred to an interruption of the nutrition of the eye, caused by the arrest of the influence of the fifth nerve, exercised through its connections with the lenticular sympathetic ganglion; but, as the inflammation ceases, when the eye is covered by fixing the animal's ear over it, it may be that they are due to the cessation of the proper protective secretion and reflex movements of the eyelids. In the rabbit, contraction of the pupil follows both division and irritation of the fifth nerve; the former, because the radial fibres of the iris, which are supplied by

this nerve through the lenticular ganglion, are paralysed; the latter, because some fibres from the sixth cranial nerve pass by the ganglion, and proceed at once to the iris; in the dog, cat, and pigeon, these effects do not ensue. The nasal mucous membrane becomes congested and bleeds easily, and the sense of smell is diminished; common sensibility, and the sense of taste at the tip of the tongue, are also affected, thus apparently indicating that the lingual branch of the fifth nerve is a gustatory nerve. The connection of the auriculo-temporal branch of this nerve with the parotid gland, and of the inferior maxillary branch, through the submaxillary and sublingual ganglia, with the submaxillary and sublingual glands, is of great importance as regards the functions of those glands; for division of the fifth nerve causes a diminution, and irritation of the nerve, a copious increase of their secretion. This is explained by the fact that irritation of the fifth nerve (and also of the facial), causes a dilatation of the nutrient vessels of the glands, and so great an increase of their activity, that they secrete an abundant but thin fluid. On the contrary, irritation of the sympathetic nerve fibres, causes contraction of those vessels, and is followed by a scanty but much more viscid secretion.

The sixth or *abducent* nerve is exclusively concerned in the government of the external rectus muscle of the eye, which turns the eyeball outwards.

The *portio dura* of the seventh nerve, or the *facial* nerve, is a purely motor and secretory nerve, any sensory fibres which it contains, being derived from its communications with the fifth and the pneumogastric nerves. Its division, or injury, is accompanied by paralysis of all the muscles of the face, excepting those supplied by the fifth nerve, i.e. the masticatory muscles. In these cases, the mouth is distorted, being drawn over to the opposite side by the unparalysed muscles; the act of blowing out a candle is awkwardly performed, and is accompanied by a puffing-out of the loose and paralysed cheek; whistling is impossible, and the attempt to smile causes a ludicrous expression; moreover, the eyelids cannot be closed, nor the skin of the forehead thrown into wrinkles on the paralysed side. The influence of this nerve on the flow of the saliva has just been mentioned. In paralysis of the orbicular muscle, which serves to close the eyelids in winking, the movements of the eyeball itself are an imperfect substitute for the action of the lids, in keeping the mucous membrane clean and moist, and in directing the superfluous tears

into the lachrymal passages; hence these escape over the cheek, and the mucous membrane of the eyeball becomes inflamed.

The *glosso-pharyngeal* nerve is chiefly an afferent nerve, being the channel of sensation for the parts to which it is distributed. Some of its fibres have the special power of conducting gustatory impressions, viz. the branches which supply the root and sides of the tongue; it is generally believed to be the nerve concerned in conveying disagreeable gustatory impressions to the medulla, and has been jocularly named the disgustatory nerve. A few of its fibres are motor, viz. those which supply certain palatal muscles.

The *vagus* or pneumogastric nerve is a mixed afferent and efferent nerve from its very origin, and does not, as some have supposed, derive all its motor fibres from the spinal accessory nerve; for irritation of the pneumogastric within the cranium, before it communicates with other nerves, causes contraction of the muscular fibres of the pharynx, of the intrinsic muscles of the larynx, and of the fibres of the œsophagus and stomach. It is a sensory, motor, and important excito-motor nerve. The sensations of pain, oppression, irritation of the air passages, want of air, hunger, thirst, and satiety, are dependent on this nerve. It has a regulating influence over the functions of deglutition, digestion, circulation, and respiration. Division of one nerve in the neck, causes difficulty of breathing, and interferes with the digestive process. Division of both nerves is fatal, after a few hours or days, in consequence of asphyxia. These results indicate, generally, the office of this important nerve, which, however, is already joined, in the neck, by branches from the glosso-pharyngeal, spinal accessory, and hypoglossal nerves. After division of the right and left nerves, the sensibility of the larynx and trachea disappears, and the reflex movements, excited through them, such as coughing, cease. Owing to paralysis of the laryngeal muscles, the vocal cords are relaxed, and the voice is rendered hoarse and feeble, or entirely fails. The inspirations are retarded, and an embarrassment of breathing is produced, ending in suffocation; this occurs more quickly in young animals, owing to the want of development of the cartilaginous structures, and the more yielding character of all the parts, so that the inter-arytenoid portion of the glottis is more easily closed. The lungs exhibit congestions, extravasations of blood, and infiltration with serous fluid; the bronchial tubes become filled with

mucus, so as to prevent the passage of air and the interchange of gases, the result being a gradual asphyxia. Irritation of the central portion of the divided vagus nerve, in the neck, produces acceleration of the movements of the inspiratory muscles, for example, of the diaphragm and external intercostals. The lower part of the œsophagus is paralysed by division of both vagi in the neck; deglutition is impossible; the food is arrested in its descent, and is vomited, and if again swallowed is once more ejected; the movements of the stomach are also arrested; the food now stationary is only digested on its surface; the secretion of the gastric juice is merely diminished, not arrested; absorption continues uninterrupted. It would appear, furthermore, that the vagus has a certain influence on the movements of the small and large intestines. Division of both nerves accelerates the action of the heart; irritation of the distal portion of the divided nerve diminishes, or even arrests, it. Section of these nerves arrests the formation of sugar in the liver; this process, however, is resumed on irritation of either of the cut ends of the nerve; the effect, in the case of irritation of the central end, is propagated through the nervous centres, and thence to the sympathetic nerve.

In a beheaded criminal, fifteen minutes after execution, it was found that the auricular contractions of the heart, which were still 60 to 70 per minute, were suddenly stopped by electrical shocks applied to the left pneumogastric nerve, the auricle remaining distended; electrical stimulation of the sympathetic, re-excited the movements. Hence it has been supposed that the vagus exercises an inhibitory action, rhythmically with respect to the sympathetic; but weak electrical currents applied to the former nerve itself, rather quicken the heart's action.

The *spinal accessory* nerve is not merely a motor root belonging to the pneumogastric, although it communicates motor fibres to that nerve; for it contains itself some sensory fibres. The exposure of this nerve by opening the cranium, is so speedily fatal to an animal, that experiments, for the purpose of determining its function, have been made by tearing out the nerve. This does not impair any of the movements which are regulated through the pneumogastric nerve, such as the respiratory movements; but swallowing is interfered with, and when both nerves are torn out, the voice ceases, the animal emitting only a bubbling noise. Extirpation of one accessory nerve causes hoarseness. Thus it appears that the

spinal accessory nerves govern the momentary and voluntary opening or closure of the glottis, and the tension of the vocal cords necessary for the production of voice, or for the exercise of general muscular effort; whilst the respiratory movements of the glottis are under the control of the pneumogastrics. Deglutition is merely rendered difficult, because the pharyngeal and œsophageal branches of the glosso-pharyngeal and vagus are still in operation. Irritation of the roots of this nerve, produces contractions in the œsophagus, pharynx and larynx, as well as in the trapezius and sternomastoid; but if the roots of the vagus are first divided, only the two last-named muscles contract. This is explained by supposing that in the former case the movements are reflex, and excited through afferent fibres contained in the spinal accessory, which convey the stimulus to the medulla oblongata, and thence along the vagus nerve. Section of the muscular branches of the spinal accessory, only partially paralyses the trapezius and the sternomastoid, because both these muscles also receive branches from spinal nerves.

The ninth, last cranial, or *hypoglossal* nerve, is purely motor, receiving, however, a few sensory fibres from the lingual branch of the fifth, the vagus, and some of the cervical nerves. Pinching or galvanising the nerve, at its point of exit from the cranium, causes violent movements in the whole tongue; section of the nerves paralyses the muscles of the tongue, without affecting either the common sensibility or the gustatory sense. Irritation of the distal portion of the divided nerve, excites contractions in all the lingual muscles; whilst irritation of the central portion still connected with the medulla oblongata, induces signs of pain, owing to the admixture of sensory fibres from other nerves, as above mentioned, external to the cranium. When one hypoglossal nerve only, or its centre of origin, is affected by disease, the tongue is paralysed on that side only, and when protruded, the tip is generally turned towards the side on which the muscles are paralysed. Besides this, one proper muscle of the larynx, and certain muscles of the neck which are connected with that organ, are paralysed by section of this nerve, which, therefore, serves not only to control the tongue, but also to adjust the larynx in speech.

Deep Connections of the Nerves, and Centres of Sensation.— On tracing the roots of the several cranial nerves into the parts of the encephalon from which they appear to spring, it is found that they all have their origin in certain masses of grey matter, which accordingly are regarded as their proper

ganglionic centres, and, in the case of the special sensory nerves, are believed to be endowed with modified forms of excitability or sensibility. The so-named ganglia of origin of the nerves of special sense, are very distinct, viz. the olfactory lobes, the optic lobes, and the auditory and gustatory masses of grey matter at the back of the medulla oblongata; whilst the nerves of common sensation and motion, cranial or spinal, arise from masses of grey matter, all situated below the optic thalami and corpora striata. It will be found, moreover, that the sensory nerves, or their sensory roots, originate from grey matter placed at the back of the medulla, in the course of the great sensory tract of white fibres, and in a line with the posterior portion of the grey matter, and the posterior columns of the cord; whilst the motor nerves, or their motor roots, spring from other masses of grey matter, associated with the great anterior or motor tracts, which pass down from the cerebral peduncles to the anterior and lateral columns of the medulla and cord. But the sensory ganglionic centres of the fifth nerves, disappear altogether opposite the pons, so that the two motor nerves above this point, viz. the third and fourth, arise from grey matter placed close to the back of the upper part of the cerebral peduncles, near the floor of the fourth ventricle, the third being higher up, some of its fibres being even connected with the corpora quadrigemina. Below the sensory ganglion of the fifth, is that of the glosso-pharyngeal, the two masses touching and blending, and suggesting an explanation of the common gustatory function of certain branches of these two nerves; below this, is the sensory ganglion of the vagus, which lies immediately above the upper end of the posterior grey matter of the cord. In front of these sensory ganglia, and nearer the centre of the medulla, are the ganglia of origin of the motor cranial nerves; that of the motor root of the fifth, being found opposite the upper part of the medulla, in close proximity with that of the sixth, and the portio dura or motor part of the seventh, which lie below and a little behind it; whilst the ganglia of the hypoglossal and spinal accessory nerves, are found a little lower down, nearer to the centre of the medulla, and above, and in a line with, the anterior grey masses of the spinal cord.

Each of these ganglionic centres, is independent as to its proper functions, as may be shown, in some cases, by artificial sections, or by the effects of disease; but, during life, they are all associated, and are subordinated to the action of the cerebrum.

On comparing the cranial nerves with a typical spinal nerve, certain homologies are evident. The sensory portion of the fifth pair, together with the motor nerves of the orbit, viz. the third, fourth, and sixth nerves, and, lastly, its own motor portion, constitute a compound cranial nerve, homologous with a spinal nerve; the glosso-pharyngeal with the facial constitute a second; and the pneumogastric and spinal accessory form a third compound nerve, like a spinal nerve; the hypoglossal is, according to this view, supposed to be a spinal nerve, sometimes having in certain animals, as already mentioned, a small sensory root. The three complete compound cranial nerves just described, pass out of the cranium *between* its component segments, as the spinal nerves emerge through the intervertebral foramina. Of the nerves of special sense, the olfactory, optic, and auditory penetrate certain cranial elements, passing respectively *through*, or into, the ethmoid, sphenoid, and temporal bones. The optic and olfactory tracts are, indeed, not nerves, but processes of the cerebrum.

Functions of the Spinal Cord.

The functions of the spinal cord have, in the first place, to be considered in reference to sensation and to voluntary motion; and afterwards, in regard to the regulation of those peculiar movements, which constitute the so-called reflex action.

As regards *sensation*, the spinal cord, like the nerves, is only a *conductor* of the effects of sensory impressions; for, when it is divided, compressed, or otherwise injured or diseased, at any part of its course, even up to the medulla, all the parts, supplied by nerves arising from it below the seat of injury, lose their sensibility, no pain being produced by pinching or otherwise irritating them. Neither is the cord itself sensitive; for, when it is divided, irritation of its lower portion produces no pain; but irritation of the upper portion of the cord, still in connection with the cerebrum, is followed by pain. The absence of pain, on irritating the lower portion which is severed from the brain, is held, by most physiologists, to be a sufficient proof that the cord itself is not sensitive, but that it is a mere conductor of the effects of sensory impressions. By a few others it is maintained, however, that when the cord is entire, as in its natural state, it really does possess true sensibility; but that, when divided, its sensations are not

consciously felt, because they cannot produce any effect in the cerebrum from which the cord is severed. Seeing that the latter opinion is one which, in the nature of things, cannot be proved, for unless a sensation be consciously felt, it cannot be positively known to exist, it seems difficult to understand on what experimental grounds such an opinion can be supported; but we shall immediately have to consider certain phenomena, which have been supposed to justify such a view.

Secondly, as regards *voluntary motion*, experiments, or accidental injuries or disease, illustrate the fact that, in this case also, the cord is a mere conductor of the effects of the voluntary motorial stimuli, and is not a centre of origin of such stimuli; for all the parts below a division, injury, or disease of any portion of the cord, are completely paralysed, or beyond the least control of the will. Severe as such an injury may be supposed to be, union of the divided cord, with complete restoration of its functions, has been observed in animals experimented upon, and, to a certain extent, in cases of injury or disease in man.

The true *sensorium*, or the seat of the realisation of sensations, and so also the true seat or centre of *volition*, are situated higher up in the cerebro-spinal nervous centres, indeed, somewhere in the cerebrum itself. The effects of sensorial impressions and volitional stimuli, pass up or down along the cord, to or from those chief centres.

We have next to examine, what are the *paths* within the cord, which these two sets of impressions pursue; in briefer phraseology, what are the *paths of sensation*, and what are the *paths of motion*, through the cord. The gradual increase in quantity, of the white matter of the cord, from below upwards, favours the idea, that its longitudinal columns are channels of conduction between the spinal nerves and the cerebrum; but the structure of these columns, is very intricate, and the grey matter, as well as the white, would seem to possess a certain conducting power for sensory impressions. The minute details of the arrangement of the fibres in the spinal cord, have been studied, by making sections of hardened cords, and then examining them under the microscope. By such means, it has been found that, of the fibres of the posterior or *sensory* roots, some ascend through the white posterior columns; others cross through the grey matter of the posterior, and even of the anterior, horn, then spread upwards, downwards, and horizontally, and enter the posterior, lateral, and anterior columns of the

same side, many of them reaching the anterior roots of the same, or of adjacent, nerves; another set decussate in the transverse commissure of the cord, cross over to the opposite side, and end, either in the grey matter, or in the posterior, lateral, or anterior columns, and even in the anterior roots of the opposite nerves; finally, many terminate in the grey matter, where they form loops, or become connected with the multipolar ganglionic cells. Hence, these fibres serve, some, as fibres of connection with the grey matter of both sides of the cord; some, to associate different nerves of the same, or of opposite sides; and possibly others, to connect the nerves directly with the grey nervous centres at the base of the encephalon. Besides this, there probably exist transverse, and perhaps longitudinal, commissural fibres proper to the cord itself.

Physiological experiments, especially those made by Brown Séquard, by dividing some portions of the cord, and leaving others, show that the effects of *sensory* impressions, pass through the white substance, for a certain distance, upwards and downwards, into the grey matter, and then cross over to the grey matter of the *opposite* side of the cord, and so ascend towards the brain. This conducting power is said to be greater in the central part of the grey matter, than in the cornua. The path of sensations, appears to be chiefly in the grey matter of the central parts, and of the posterior half of the opposite side of the cord. The white posterior columns do not appear, in any way, to assist in conveying the effects of sensory impressions upwards. The experiments, from which these conclusions are drawn, consist, first, in dividing or destroying the posterior white column with the point of its cornu of grey matter, in which case, sensation is retained in the parts below the injury; and, secondly, in preserving the posterior column and grey cornu, and dividing or crushing all the rest, when sensation is lost. To show the divergence of the paths of sensation, upwards and downwards, the ascending and descending posterior roots of the nerves, are traced far into the grey matter, which is then cut, first above, and then below, the nerves; it is found that sensation is not completely destroyed, till the grey matter is cut in both directions. So also, when the posterior columns are divided transversely, both surfaces continue to conduct sensory impressions, showing the descent of these impressions in the lower part of the cut cord, before they cross over to the opposite side. In proof of the decussation of the path of sensations, it is found that, on dividing the right half of the

cord, in the neck or back, sensibility ceases on the opposite side of the body only, whilst motion is destroyed only on the same side. An additional remarkable result takes place, viz. that, on the same side as the cut, especially when this is in the posterior portion of the cord, the sensibility is, after a few hours, much exalted, and remains so for many days, or, to a slight degree, for months. This effect, it is conjectured, is due to a dilatation of the minute vessels of the parts on that side, through the suspension of the action of certain sympathetic vasi-motor nerves, which are connected with the injured part of the cord. This increase of sensibility, or *hyperæsthesia*, is accompanied by fulness of the vessels, and by an elevation of the temperature of the part. It may be due to simple inflammation, propagated from the wounds inflicted on the cord, and on the soft parts and bones, in exposing the cord itself. It has been seen after section of the anterior or motor columns alone. It has also been stated, by able experimenters, that in dividing the cord on one side, there is a certain diminution of sensation on both sides, but a greater one on the opposite side; any remaining appearance of sensation, in the latter case, being dependent on painful reflex movements.

It is believed by Brown Séquard, that different kinds of sensory impressions, have different channels, none of which are substitutes for the others—touch, pain, the sense of temperature, and the muscular sense, each having its own channel. Schiff also states, that the higher form of common sensibility, which is named tactile sensibility, as distinguished from a mere sense of pain, travels up along a different path, to that of ordinary sensation. According to him, tactile sensibility is lost on the cut side, so that its path is in the white columns of the same side, and does not decussate, or pass over, to the other side; whereas the path of common sensation, is through the grey matter, in which the impressions are diffused in various directions. He further adds, that it is the common sensibility only, and not the other forms of sensation, which is exalted on the same side, and diminished on the opposite side; and that this effect is only temporary. Some singular results follow a median section down the spinal cord. According to Brown Séquard, if the cord be cut along the middle line in the lumbar region, sensation is lost, on both sides, in all the parts below the cut; but if the section be higher up, sensation is lost only in the parts supplied by nerves from the corresponding piece of the cord, and not in the parts lower down. These results

appear to show, that the decussation of the paths of sensation, in reference to all the parts below, takes place in the lumbar enlargement of the cord, and that therefore both sides are paralysed as to sensation; whereas, higher up, the decussation of the paths of sensory impressions from the parts below, has already taken place, and so those are not cut in the median section, which destroys only the decussation of the nerve roots, or sensory paths of the adjacent nerves. Other observers conclude, that this decussation of the paths of sensation, is not quite complete, but that some sensory fibres may pass up in the grey matter, or in the posterior white columns, of their own side; for they have found that, after median longitudinal division of the cord, some sensory impressions still pass up on their own side. (Schiff.) It may be, that the arrangement of the fibres of the cord, differs in the different species of animals, which have been the subjects of experiment. It will immediately be seen, that a median section down the spinal cord, does not paralyse the muscles, or affect the voluntary movements. It has been found, that so perfect, or generally diffused, is the conducting power of the grey matter of the cord for sensory impressions, that the smallest portion left, either in a transverse or longitudinal direction, is sufficient to conduct, though in a limited degree, sensory impressions across to the opposite side, or in an upward direction. This facility of conduction caused Schiff to compare the grey matter to a mass of fluid, in which vibrations are transmitted equally in all directions. From the fact, that the grey matter of the cord, is itself insensible, though a conductor of sensory impressions, he named it the *æsthesodic substance*, because it is the path of sensory impressions (αἴσθησις, aisthesis, *sensation*, and ὁδός, odos, a *path*), and yet not sensitive itself.

The path of the *voluntary motorial* stimulus has next to be considered. The anterior or motor roots of the spinal nerves proceed from fibres, which, as already mentioned, may be followed through the anterior cornu of the grey matter of the cord; some pass upwards and downwards into the anterior and lateral columns; others come into relation, in the grey matter, with the fibres of the posterior roots of the same side; whilst another set cross over to the opposite side of the cord, decussating there with fibres coming in the other direction, and ending in the anterior and lateral columns of that side, or even in the anterior roots of its nerves; many come into close connection, or are continuous, with the posterior roots of the

same side; and, finally, many end in the grey matter, where they become connected with the multipolar cells. These fibres, like those of the posterior roots, resolve themselves into proper fibres of origin in the cord, fibres of association of the nerves of the same and opposite sides, and longitudinal fibres, which probably connect the nerves directly with the encephalon.

The path of the voluntary motorial stimulus appears to be downwards, through the anterior column and adjacent part of the lateral column of white substance, and perhaps through the anterior cornu and grey matter. When the posterior columns are divided transversely, no apparent loss of volitional power takes place. If, however, the anterior and lateral columns be cut across, the parts below are paralysed, on the same side, as regards voluntary motion. If the section be made high up in the cord, division of the anterior white columns was said, by Bell, to have the same effect; but Brown Séquard maintains, that in this region the lateral columns convey the volitional impulses, the grey matter being also slightly concerned in this act. If the cord be cut completely across, and the cut end of the lower portion, which is detached from the brain, be irritated on the section of its antero-lateral column, convulsive movements will take place in the muscles below; but if the posterior part of the section be irritated, no movements occur. And it may be added, that if the cut ends of the anterior columns of the part still in connection with the brain, be irritated, no movement takes place; whereas, if the cut ends of the posterior columns be irritated, pain is produced.

A most remarkable accident, which occurred to a gendarme in Paris, has supplied experimental proof of the paths of voluntary motion and sensation, in the human subject. He was struck in the back of the neck by a knife; his right arm was slightly, and the right half of the trunk and the right leg completely, paralysed, as regards voluntary motion; whilst sensation was quite perfect in all these parts. He died in four days. The point of the knife was found in the vertebral canal, having passed through the arch of the sixth cervical vertebra on the right side; it had exactly divided only the anterior column, the lateral column, and the adjacent part of the grey matter on the right side of the spinal cord.

It remains to notice that, as already observed, the median longitudinal section of the cord, in animals, does not destroy voluntary motion. It should also be remarked, that in certain

cases of disease of the spinal cord, the posterior columns of the cord have been found disorganised, without there having been any impairment of sensation. As the term æsthesodic has been applied by Schiff, as already mentioned, to that substance of the cord, which is concerned in the conveyance of sensory impressions, so, for similar reasons, the term *kinesodic*, (*κίνησις*, kinesis, *motion*, and *ὁδός*, odos, *a path*) has been employed to designate the substance concerned in the conduction of motorial impulses, a property, which, he likewise believes, it can exert in any direction.

The sum of our information on the whole subject is this:—First, that the paths of *sensory* impressions reach the grey matter of the cord, the interposition of which is regarded as an essential condition of sensitive conduction; diffusing themselves in the grey matter, they pass to the opposite side, and then ascend towards the brain; so that they decussate even at the lowest part of the cord. Secondly, that the paths of *voluntary* motion descend from the brain, not through any intervening grey matter, but along the white fibres of the anterior and lateral columns, perhaps also through white fibres lying in the adjacent grey matter of the same side of the cord, and that they do not decussate in it. Numerous fibres certainly cross over from one side of the cord to the other, in the anterior columns; but these, which belong to the anterior roots of the nerves, are perhaps concerned in the reflex, and not in the voluntary movements. This difference in the paths of sensory and motor impulses along the cord, and the decussation of the former within it, explain cases of disease of the cord, in which there are observed, muscular paralysis of one limb, and anæsthesia or paralysis of sensation in the other.

Considered as an anatomical question, it does not seem possible that all the fibres, either of the sensory or motor roots of the spinal nerves, can ascend directly up to the seats of common sensation and of volitional impulse, in the brain; for the mass of the cord is not increased as it ascends, *in proportion to the number of nerves* which join it; indeed, *most* of the *fibres* of the nerves appear to end in the cord itself; and many of its own longitudinal fibres appear to be commissural, serving to connect the nerves with many segments of the cord, or its own segments with each other. Many of the nerve fibres appear thus to be concerned in the exercise of functions dependent on the cord itself, acting as a special nervous centre. The propagation upwards of sensational

impressions, is probably accomplished chiefly through the grey matter, by indirect electrotonic changes excited in it; whilst the volitional impulses descend chiefly through longitudinal fibres, indirectly excited from above. The conducting power of the grey matter, moreover, in both cases, seems now to be well established ; it contains, however, many intermixed white fibres. It has been observed, that the posterior columns of the cord are highly sensitive to stimuli on their surface, but not in their interior ; whilst the antero-lateral columns are not sensitive either on their surface, or in their interior. (Chauveau.)

The preceding experiments demonstrate the conducting properties of the spinal cord, both as concerns its grey and its white substance, and in reference both to sensory and to voluntary motor impressions; and they show, moreover, by the complete annihilation of voluntary power in the parts below a cross section through its substance, that it does not originate voluntary motorial stimuli, nor effectually feel sensorial impressions. But, in regard to motion in general, we shall find that the cord is a governing centre for a particular class of *involuntary movements*, which have repeatedly been mentioned, viz. the *reflex movements*; and, in reference to sensory impressions, we shall find that the cord, when in a state of integrity, can not only conduct such impressions to the common sensorium, but may also *transfer* them from nerve to nerve, and cause them to *radiate* from one branch of the same nerve to other branches.

The *transference* of sensation from one nerve to another, through the cord, is illustrated by the occurrence of pain in the knee joint, in cases where the disease is actually in the hip, or by the feeling of pain in the heel, when the kidney is the seat of irritation, or by the pains felt in the limbs, in certain examples of disease of the brain. In these cases, the sensory impressions are said to be transferred from nerve to nerve, through their connecting bond of grey substance in the cord; for they have only been noticed where the nerves retain their connection with their proper grey centres. The *radiation* of sensations from one branch of a nerve to another, is illustrated in the case of neuralgic affections proceeding from a local injury to one branch of a nerve, say of the skin of the hand, and also when a nerve entangled in a cicatrix, or in the sides of a growing tumour, causes pain, not only in the part, but also along the track of other branches of the same nerve ;

these phenomena are observed only so long as the nerves are in connection with their grey centres. It is open to question, whether a very powerful stimulus to one nerve fibre, may excite adjacent fibres, as, for example, in the interlacing parts of a plexus, and so produce pain referable to distant parts; we have elsewhere seen, that a stimulus applied to one nerve, may communicate itself to a neighbouring nerve (p. 286). This occurs more commonly, when the nervous centre connecting the nerves, is in a particular condition of excitement. Thus, in a highly exalted state of the nervous excitability, as, for example, in the condition of inflammation, or of irritation produced by strychnine, the ordinary insulation of the nerve fibres, may, as it were, be broken through, and then stimuli applied to one set of fibres may excite adjacent ones directly, without the intermediation of the grey matter of their common nervous centre.

It remains to notice the reflection of impressions, brought by *afferent* fibres to the cord, upon *efferent* fibres proceeding from the cord, producing what are called *reflex actions* or movements, and constituting what is known as the *reflex excito-motory* power of the cord. The existence of such a controlling or regulating power in the cord, over the muscles supplied by nerves issuing from it, is shown by the fact, that a decapitated lizard or frog will remain standing on its feet, and will manifest special movements, if the skin be irritated. On further division and subdivision of the trunk and tail, each segment of the lizard, containing its portion of the spinal cord, still continues to exhibit similar movements. Again, when the spinal cord of a frog is divided, all voluntary motion, as we have already seen, ceases in the parts below. If the posterior columns of the severed portion of the cord, be now irritated, convulsive movements follow in the muscles below and above, resulting from the indirect artificial stimulation of the motorial tracts and motor nerves proceeding from them, and not from a direct irritation of those tracts, the effects of which would be limited, as in the case of a pure motor nerve, to the muscles supplied from the stimulated portion of the cord. But, furthermore, movements may be excited in those muscles, by the application of a stimulus to some distant and excitable part of the skin of the animal; the stimulus employed, first excites the extremity or trunk of an afferent or so-called sensory nerve, the effect of the impression so produced, passing up to the grey nervous centre, the cord, and thence being, as it is specially termed, *reflected*

on to certain efferent, or so-called motor, fibres, and so reaching the muscles which are excited to contract. This is the mechanism of all reflex movements. All require for their execution, an afferent nerve, an efferent nerve, and an interposed grey nervous reflecting centre, or centre of reflection. The stimulus excites the afferent nerve, this the reflex centre, and this again the efferent nerve; hence the term *excito-motor*, or excito-motory, applied to the reflex phenomena and acts. They are also named *automatic*.

The experimental illustrations just given, in the cases of decapitated animals, or of animals the spinal cord of which has been divided, show the independence of these acts, of the cerebrum, or of any cerebral interference; they prove accordingly, that the spinal cord is, in regard to them, an independent centre of nervous action. These movements are strictly involuntary, and they may occur quite independently of sensation and consciousness; they are not irregular or convulsive movements, such as follow the pinching or irritating a motor nerve, or the motor columns of the cord; but they are definite and regulated movements, depending on the distribution of the afferent nerve, to the ends of which the stimulus is applied, and on the particular efferent fibres, upon which the effects of this stimulus are reflected.

These reflex movements are even more extensive and powerful, when the spinal cord is separated from the brain, or seat of volition, than when the cord and medulla are still connected with it. According to some, this is owing to the loss of a controlling power exercised by the brain; but according to another view, it is rather due to the fact, that, when the cord is severed, the whole force of the excitation is necessarily thrown upon the ganglionic centres of the cord alone. Reflex movements are more easily excited by irritation applied to the free extremities of the afferent nerves, as to the skin of a frog, than by stimuli, even of a stronger kind, applied to the trunks of those nerves, though the pain in the last case may be as great or greater. This is another proof, that there is no necessary relation between sensation and reflex action. So in cases of diminution of sensation, and loss of voluntary motion, in the lower half of the body, the controlling power of the brain being absent, the reflex action is increased, and slight stimulation of the skin, unfelt by the person, produces more powerful reflex movements, than the stronger stimuli of pinching and pricking, which may be felt by him. The phenomena observed,

after injury of the cord, further prove, even in the human subject, that the conveyance of volitional impulses, may be completely destroyed by a certain lesion, which nevertheless does not interrupt the transmission of reflex, or excito-motor, impressions on its afferent nerves ; and, further, that the effects of such impressions, may be widely diffused through the cord. It frequently happens that such reflex phenomena, after injury, do not manifest themselves, or at first only feebly, but that subsequently they become stronger, when the effects of concussion, for example, have passed off, though not so far as to restore the volitional power.

Reflex movements ordinarily have a special object or design, and are therefore said to be *purposive*; a character which, as we shall frequently find, by no means implies that they are either accompanied by sensation, or directed by the will. Most frequently, they may, in general terms, be said to have a *conservative* object in the animal economy. Besides the example of reflex movements, performed through the cord, exhibited in the hinder limbs of the frog, the spinal cord of which has been divided, instances of reflex movements, performed through the cord, may be adduced in the human subject, when unconscious, as in sleep, or under the influence of chloroform, or when awake, in a state of disease or even in health. The withdrawal of the feet, when tickled during sleep, the flinching of a patient under chloroform, from any cause of irritation applied to the surface, also the involuntary raising of the foot, from the pricking of a needle, and the sudden withdrawal of the hand, on which hot sealing-wax has fallen, are instances of involuntary reflex movement taking place under different circumstances. In the two latter cases, conscious sensation accompanies the reflex acts, which are therefore designated *sensori-motor*; in the two former cases, there is a greater or less approach towards a suspension of sensation; but it may not be wholly lost, though the memory of it is not retained. In the first instance, that of sleep, a similar difference of opinion may obtain, in the mode of interpreting the phenomena, conscious sensation being held, on the one hand, to be merely blunted, or, on the other, to be entirely suspended. But there remains another set of examples, in which there can be no doubt of the complete annihilation of sensation, and of all its attendant consequences, although active reflex movements can be produced by external or even internal stimuli. Thus, in injuries or diseases which cause compression,

laceration, or softening of the spinal cord, to such an extent as completely to destroy both voluntary power over the limb, and likewise all sensation in it, violent reflex movements may be excited, in the so completely paralysed limb, by the application of stimuli to the extremities of the afferent nerves, as by tickling, pricking, or electrifying the skin of the soles of the feet, when a movement of withdrawal will take place, over which the patient has no control, as he would ordinarily have, if the cord were sound, and of which, as well as of the sensations which the stimuli are calculated to produce, he has no perception or consciousness whatever, provided his eyes be closed. An instance is recorded by John Hunter, of a man whose spinal cord was ruptured. Being asked, when his feet were irritated, whether he could feel the irritation which excited them to move, he replied, 'No, but you see my *legs* do.' Such cases demonstrate perfectly, not only the involuntary character of the reflex movements in question, but also prove that they may take place without conscious sensation. The apparatus concerned in their production, is exactly similar to that of the movements excited by irritation of the skin, in the hind limbs of the frog, the spinal cord of which has been divided; that is to say, it consists essentially of *afferent* or *incident* nerves, of a *reflex grey centre*, and of *efferent* or *motor* nerves. In certain experiments on the frog, the purposive character of these movements, even where there can be no suspicion of volition or consciousness, which must be one and indivisible, is well illustrated. Acetic acid, which powerfully stimulates these animals, when applied to the inner side of the knee joint, or to the side of the abdomen of a *decapitated* frog, excites the animal to rub that portion of the skin with the same foot; and, if now that foot be cut off, similar attempts are then, more or less effectually, made with the opposite foot.

Lastly, the necessity for the interposition of a reflex grey centre, between the afferent and efferent nerves, is shown likewise by experiment in animals, and by observation in cases of injury and disease in man. For if the severed portion of the spinal cord in the frog be destroyed, as by passing a wire down the spinal canal, stimulation of the nerves of the skin will no longer produce reflex movements, although the contractility of the muscles, and the excitability of their efferent nerves, still remain active, as may be shown by pinching one of those nerves, when the muscles, to which it is distributed, will immediately contract. So, too, in cases of disease of the

spinal cord, when the distal part, below the seat of any disintegrating injury or disease, becomes itself softened, and so loses its vital properties, reflex movements can no longer be excited in the lower limbs, by stimulating the skin. An afferent nerve cannot therefore convey, or transmit, the effects of a stimulus upon it, to an efferent nerve directly, but can only reflect those effects indirectly, through interposed grey matter. From this, it has been inferred that the nerve cells of the grey matter, are, in some way, specially concerned in this office of reflection, but it is not yet known how they act. The most prevalent opinion is, that a particular afferent fibre ends, as described in page 56, in one of the processes of a nerve cell, and that the efferent fibre arises from another process of the same cell. Where the cells have more than one process, more than one afferent or efferent fibre may, it is thought, be so connected with it. Or a succession of nerve cells may be interposed between the incident and the motor fibres, and so may extend or spread the effect of the stimulus. Again, it is held by some, that perhaps the reflex office of the grey matter, is effected by the mere proximity of the nerve fibres passing through it, between or amongst the nerve cells, without there being any direct connection between them.

A further question arises as to whether there are special afferent fibres concerned in conveying a reflex stimulus, different from those afferent fibres destined to convey the sensory impressions. It is certain that, if this be so, no anatomical difference, between the several afferent fibres in the posterior root of a spinal nerve, can be detected. It appears probable, however, that their difference in function, that is, whether they convey the effects of sensory impressions to the grey matter of the cord, thence to be conducted to the brain, or whether they convey the effects of stimuli to the grey matter of the cord, thence to be reflected on to the efferent reflex nerves, depends upon the nature of their connections with the cells of the grey matter. Neither can any structural difference be found amongst the efferent fibres of the anterior roots; and it is presumable, therefore, that the particular efferent fibres, concerned in voluntary movements, and in reflex involuntary movements, owe their special mode of action to the fact, that the former descend continuously from the *cerebrum* (that is, from the corpora striata), whilst the latter probably originate in connection with the nerve cells of the grey matter of the cord. It appears, moreover, both from experiment and from

observation in cases of disease, that the posterior white columns of the cord, and the contiguous grey matter, the nerve cells of which are peculiar, may have some special relation to the reflex function. The various instances, in which the spinal cord acts as a reflex nervous centre, and some further points concerning these reflex movements, will be hereafter considered.

It remains to be noticed, that the spinal cord exercises, probably by a continuous reflex action, a permanent influence on the muscles, upon which the so-called *tonicity*, or *tonic state*, of those organs, depends; for when, in an animal, the cord is destroyed, or carefully removed from the spinal canal, all the muscles become atonic or flabby, and the habitually contracted condition of the sphincters is lost. The rigor mortis, nevertheless, takes place as usual. This tonicity, or tension, is supposed to depend on a slight but constant exercise of a stimulus, originating in the cord, upon the entire muscular system. It does not depend on the brain, for decapitated animals will retain their position; but the limbs immediately become flaccid and fall asunder, when the cord also is destroyed. It is from loss of this tonicity in the paralysed muscles of the face, that, independently of the will, the features are drawn over to the opposite side, by the still healthy muscles. That this effect does not depend on loss of the contractility in the paralysed muscle, is shown by the fact that the muscle will still contract, on the application of a direct stimulus.

Irritation of the cord of a recently decapitated animal, increases considerably the force of the heart's beats; it also accelerates the contractions of the intestines, ureter, and bladder, and even of the small arteries. These phenomena indicate a partial dependence of those organs on the spinal cord, through the intervention of the sympathetic nerves, which constitute the only channel of communication between them and the cord.

Partial extirpation of the cord from animals, is borne for a very long time, and, in birds especially, is followed by loss of sensibility and mobility in the corresponding parts of the body. Complete removal of the cord, in mammalia, causes death, only after one or two days, provided hæmorrhage be guarded against. Partial destruction of the cord by a wire is much more speedily fatal, death occurring in a few hours, and more quickly, the nearer the injury to the cervical region; total destruction of the cord, by the same means, is almost instantaneously fatal.

Functions of the Medulla Oblongata.

In a physiological as well as in an anatomical point of view, the medulla oblongata is to be regarded as a continuation upwards of the spinal cord; but owing to the importance of the organs, the nerves of which proceed from it, its functions are of greater consequence than those of the cord. It is further remarkable as being the seat of the *decussation*, or crossing from one side to the other, of the paths of the voluntary motorial stimulus from the cerebrum above, to the spinal cord below; this decussation of the motor tracts, occurs almost entirely at the lower part of the medulla oblongata. (Brown Séquard.)

The medulla oblongata acts, like the cord, as a *conductor* of the effects of *sensory* impressions upwards, from the cord to the cerebrum; the paths of such sensory impressions, are probably, on grounds of analogy, through the grey matter, and the continuations upwards of the ascending fibres of the posterior pyramids, and not through the restiform bodies, which pass up to the cerebellum. These paths do not again decussate in the medulla, having already crossed over in the grey matter of the cord. The medulla oblongata may, also, *transfer* the effects of sensory impressions, from one nerve to another; as when any irritation in the stomach, acting on the vagi nerves, produces sympathetic headache, or pains in other parts of the body. Moreover, radiations of sensation may take place through the medulla oblongata, as when the pain from a single decayed tooth, is transferred to other branches of the fifth nerve, and causes pain in the corresponding tooth in the other jaw, or in various parts of the same side of the face and head.

The medulla oblongata likewise acts as the *conductor* of the effects of the *voluntary motorial* stimulus passing down from the brain, onwards to the spinal cord and spinal nerves. The paths through which this conduction takes place, are the fibres of the anterior pyramids, division of one of which produces in an animal, paralysis of one side of the body (Magendie); whilst irritation of these, is not followed by indications of pain, as is the case, when the restiform bodies are simply touched. The fibres of the anterior pyramids decussate in so remarkable and complete a manner, that the motorial stimulus, proceeding down the peduncle of one cerebral hemisphere, crosses completely over in the medulla, to the opposite side of the

cord, at the so-called decussation of the anterior pyramids. Thus, in artificial division of one-half of the spinal cord of an animal, paralysis of motion occurs, as already mentioned, on the same side of the body; whilst if the section be made opposite the decussation of the anterior pyramids, in the medulla oblongata, paralysis of the muscles follows on both sides; but if the section be still higher, in the very highest part of the medulla oblongata, the paralysis happens only on the opposite side of the body. These results are confirmed by other experiments, and by observations, in disease, in man; and these are of high importance, for sections of the medulla oblongata itself, especially of its posterior parts, are often so immediately fatal, owing to its being the centre for the regulation of the respiratory movements, that time is not allowed for the development of the effects, as regards the voluntary movements. Thus, when one hemisphere of the brain is removed in an animal, there is a diminution of power on the opposite side; and when the peduncle of one hemisphere is removed, there is a total loss of voluntary power on the opposite side of the body; so, again, effusion of blood into, or softening of, the substance of one peduncle, or of the parts above it, in man, is followed by paralysis of motion, with or without paralysis of sensation on the opposite side; whereas paralysis of those muscles, the nerves of which proceed directly from the pons or peduncles of the cerebrum, that is, from above the place of decussation of the motor columns in the medulla oblongata, is on the same side as the injury or disease; for example, cases of extravasation of blood into the left corpus striatum, or left hemisphere of the brain, exhibit, during life, paralysis of the right limbs, but usually of the muscles of the left side of the face; there may sometimes be paralysis of the opposite side of the face also, the reason of which is not known. Decussation of the paths of the voluntary motorial stimulus in the medulla oblongata, is thus abundantly proved.

Many *reflex* functions are performed by the medulla oblongata, in common with the spinal cord. The afferent nerves connected with it, supply all the important surfaces and organs at the upper part of the body; viz. the skin of the face, the mucous membranes lining all its cavities, the parts of the organs of the senses endowed with common sensibility, and the lining membrane of the pharynx, larynx, windpipe, and bronchial tubes; lastly, they give branches to the heart and lungs, as well as to the œsophagus and even the stomach.

These fibres accordingly, bring the effects of excitant stimuli, from all those surfaces and parts, to the great and important reflex centre, formed by the grey matter of the medulla oblongata, from which the effects are reflected, along certain special efferent motor fibres, on to various muscles, which, then contracting, cause reflex movements of a most extensive, definite, and important kind.

Some of these movements assist in the performance of the functions of special sense, as, e.g. the movements of the pupil. Others are conservative or protective, in regard to the sensory organs: for example, the closure of the eyelids is a reflex act; it can even be excited in animals, in which the functions of the brain have been entirely suspended or destroyed, by irritating the margins of the lids by a feather. Other reflex movements protect the respiratory apparatus; and some are absolutely essential to life, as is the case with the movements of deglutition, and especially with those of respiration; for such movements as the acts of sneezing and coughing, part of the act of swallowing, and all the respiratory movements, are of an involuntary reflex nature. They are all performed under the influence of the medulla oblongata, the injury or destruction of which, impairs or arrests them.

In reference to the respiratory functions and movements, this influence has been specially demonstrated by experiments on animals, which have yielded both negative and positive results. Thus, even in warm-blooded animals, all the parts of the brain have been gradually cut away from above, down to the medulla oblongata, and the spinal cord has then also been detached below it, and yet respiration has continued for a short time (Longet); and in the frog, both the brain and spinal cord have been removed, and respiration has been long sustained, provided that the medulla oblongata remained uninjured. Again, the medulla oblongata itself has been alone destroyed, when respiration was instantly arrested, the animal dying asphyxiated. It is sufficient for a very small portion of the back part of the medulla, in the floor of the fourth ventricle, to be destroyed, in order to produce this effect, and indeed the destruction of a very minute point, hence named the *vital knot* (*nœud vital*), has been deemed sufficient for this purpose. But there seems reason to think, that the part concerned as a centre in governing respiration, is of greater extent; it is believed to correspond with the portion from which the deep roots of the pneumogastric nerves take their origin, which occupies the back part of the medulla; for the

restiform bodies and the pyramids, may be removed without interfering with the respiratory acts. A transverse section through the grey matter of the medulla oblongata, at the point of the calamus, suddenly stops the respiratory movements; but after a longitudinal median section of the medulla, these continue. Hence both sides of the body possess their proper respiratory nervous centre. Irritation of the medulla oblongata diminishes the number of the respirations; a result also produced by general pressure on the brain, the effects of which are transmitted to the medulla. The paths of conduction of the motor impulses concerned in respiration, named, by Sir C. Bell, the *respiratory tracts*, are located in the white fibres of the lateral columns of the cord. (Bell, Schiff.) The office of the medulla oblongata, as the controlling centre of respiration, affords an explanation of its importance in regard to the vital activity generally. Through it, the heart is indirectly, and also directly, affected, for the vagi nerves, which regulate the heart's movements arise from this part. Galvanic irritation of the medulla, like that of the vagi nerves, causes temporary arrest of the heart's actions; its destruction diminishes the frequency and strength of those movements.

There is reason to conclude, from analogy, that the reflex movements of deglutition must likewise have their special governing centre, which is supposed to be placed at the back of the medulla, near the vital knot.

As a reflex centre of a more general kind, the medulla oblongata is further regarded as the seat of excitation of symmetrical epileptic seizures, such as occur after ligature of the great vessels of the neck.

The medulla oblongata is probably also a centre for certain parts of the sympathetic system; and a cross section through the restiform bodies, like division of the posterior columns of the cord, is followed, probably from similar reasons, by an exalted sensibility of the trunk and limbs.

Like the reflex acts of the spinal cord, those which take place through the intervention of the medulla oblongata, are likewise independent of the will, and are not necessarily associated with consciousness; for an animal will suck an object placed between its lips, or swallow a mass of food placed on the back of the tongue, or close the eyelids, if these be irritated, even though the functions of the brain be suspended or destroyed. Persons in a profound state of comatose unconsciousness and insensibility, from the effects of concussion of the

brain, or of chloroform or opium, will perform the same acts, and so too will acephalous monsters. It has also been shown that the contractile movements of the pupil, produced by the action of light, and intended for protective purposes for the retina, and which are ordinarily accompanied by the special sensation of light, will occur in cases of amaurosis, a disease characterised by alteration and consequent insensibility of the retina, and in which there is absolute blindness. A strong light also sometimes causes sneezing, by a reflex action through the optic nerve, the cerebro-spinal centres, and the nerves which govern the respiratory movements; this movement is automatic and *sensori-motor*, for it is accompanied by pain.

Furthermore, the medulla oblongata is, in some way, concerned in the special senses of *hearing* and *taste*, containing, as it does, the deep origins of the portio mollis of the seventh pair or auditory nerve, of the glosso-pharyngeal nerve, and of the gustatory fibres of the fifth pair. Its grey matter either constitutes the special centres of the auditory and gustatory senses, the effects upon which, are afterwards transmitted to the common sensorium in the cerebrum; or it serves as an essential, but non-sensitive, conducting path of the effects of sonorous vibrations or of gustatory impressions, in their way upwards to the cerebrum.

It has been supposed that the grey matter of the *olivary bodies*, with which the roots of the hypoglossal nerves, are said to be connected, has some special office in the government of the tongue and adjoining parts, in the motions necessary to speech (Schroeder Van der Kölk); but this view has not yet received the general sanction of physiologists.

The formation of sugar in the liver is increased, by puncture even on one side, of the back of the medulla oblongata (Bernard), to such a degree, that the urine becomes saccharine. Whether this is indirectly owing to an interference with the respiration, or to some action on the secreting power of the liver itself, is not known.

Functions of the Pons Varolii, Cerebral Peduncles, and the grey masses at the base of the Cerebrum, viz. the Corpora Striata, Optic Thalami, Corpora Quadrigemina, Corpora Geniculata, Pineal, and Pituitary Bodies.

In the first place, setting aside the transverse fibres of the pons, which form the middle peduncles of the cerebellum, and

also leaving out of consideration, the superior and inferior peduncles of that organ, the latter being the continuation upwards of the restiform bodies, we may regard the longitudinal fibres and the grey matter of the *pons* and cerebral peduncles, as physiological extensions upwards, upon an amplified scale, of the white and grey elements of the spinal cord and medulla oblongata. They accordingly receive, conduct, or transmit the effects of *sensory* impressions, upwards to the cerebrum; and, in particular cases, probably also transfer and radiate such impressions. They also conduct the *voluntary motorial* stimulus, downwards from the cerebrum to the medulla and cord. The paths of sensation are probably through the grey matter and white fibres of the central and posterior portions of the pons and of the cerebral peduncles; whilst the paths of motion are down through the white fibres forming their anterior or under portions. Furthermore, the grey matter of these parts, forms reflex centres for the performance of most extensive and powerful reflex acts, being, in this sense, quite as energetic as the medulla oblongata and cord. Some of these reflex movements are of a local kind, such as those which regulate certain of the movements of the pupil; others are of so general and purposive a character, as to have led to the supposition that here, at length, we arrive at a portion of the nervous centres, in which not only *conscious sensation* may be realised, as supposed by Longet, but in which some feeble *mental directive power* may be exercised. But this is not proved.

In animals, in which, the cerebrum and cerebellum being taken away, the pons and medulla oblongata are left uninjured, and connected with each other, cries and attempts to remove the objects of irritation, have been found to follow pinching the tail, and the application of ammonia to the nose; if left quiet, the animal remains motionless, but if put into an uncomfortable position, it immediately resumes a more easy one. All such movements, however, cease, when the pons is removed from the medulla. (Flôurens, Longet.) The movements appear to be as perfect as the natural sensori-motor reflex movements, and resemble the instinctive movements of animals, but they are not really voluntary.

Experiments on the pons and cerebral peduncles, are followed by remarkable results. Thus, irritation of the deep parts of the *pons*, causes convulsions in various regions of the body, and, if the brain be left, obvious signs of sensibility.

A section of the transverse fibres of the pons leading to the cerebellum, on one side, causes most curious rotatory movements on the part of the animal, which turns *towards* the injured side, contrary to what happens in certain other examples of rotation, to be presently mentioned, produced by sections of other parts of the nervous centres. Section of the corresponding fibres on the opposite side, arrests this rotatory movement. Division of these fibres, on one side, also produces a downward movement of the eyeballs on the injured side, and convulsive, rolling movements in the eye of the opposite side. Lastly, a hyperæsthesia similar to that which follows sections of the spinal cord, especially of its posterior portion, occurs after sections of the back or front of the pons; but this is noticed on the opposite side of the body, and not on the same side, as is the case when the cord is injured.

The *cerebral peduncles* are, like other portions of the longitudinal parts of the nervous centres, conductors of sensorial, voluntary, and reflex impressions, upwards and downwards, along special sets of fibres, set apart for each function. Thus, the sensorial paths are connected with the optic thalami, and the motor tracts with the corpora striata and corpora quadrigemina. Division of both peduncles, is followed by complete loss of sensibility and voluntary movements in the body. When one peduncle is partially divided, remarkable rotatory movements ensue, *from* the injured *to* the sound side, which have been attributed to a loss of the controlling power of the cerebrum, over the half of the body opposite to the injury; the circles of movement are larger, the nearer the section is made to the cerebrum. Complete division of one peduncle, causes the animal to fall on the opposite side, because it paralyses that side, though the reflex functions remain intact.

Irritation of the peduncles, after the brain has been removed, causes contractions in the muscles generally, and also in the stomach, intestines, and bladder; these effects show conductive power, partly through the pons, medulla, spinal cord, and spinal nerves, and partly through the sympathetic, which is connected not only with the medulla and cord, but also with parts of the brain higher up.

As to the grey masses, sometimes named the cerebral ganglia, found at the base of the brain, the grey matter of the *corpora quadrigemina*, appears to be associated with the function of sight; for removal of these parts, causes blindness, which likewise usually follows their destruction by disease.

Atrophy or wasting of these bodies, may result from atrophy of the eyes. The destruction of one, causes loss of sight in the *opposite* eye, and temporary debility of the opposite side of the whole body. The corpora quadrigemina are also highly irritable, and exercise reflex functions of an extremely active and important kind. Thus, irritation of both, or even of one, of these grey centres, produces contraction of both pupils, and, during life, such movements are doubtless caused by impressions conveyed from the retinæ, through the afferent fibres of the optic nerves and tracts; and the experiment last mentioned, on one of these bodies, is regarded as a proof of the transmission of impressions from both retinæ, backwards through the optic commissure, along both optic tracts. Partial removal of the corpora quadrigemina, produces partial blindness of a temporary kind, debility of the muscles on the opposite side of the body, and sometimes giddiness, or slight rotatory movements; possibly from the interference with the sense of sight. Their complete removal is followed by total blindness, and by dilatation and immobility of the pupil. The general consciousness is not interfered with. Besides the slight rotatory movements just mentioned, general convulsions sometimes follow experiments on these parts; but these are both supposed to be owing to unavoidable injury, or irritation, of deeper seated parts. That the corpora quadrigemina are connected with the exercise of the function of sight, is therefore undoubted, and it is probable that they are either the actual centres of visual sense, or the essential paths for the reception and conduction of visual impressions to a common sensorium. It is, perhaps, through this office, that the effects of injuries of these centres, on the general muscular movements, may be explained, for vertigo may be produced by blinding one eye, or by causing the humours of one eyeball to escape.

The office of the *corpora geniculata* is unknown; from their anatomical connections, they might be supposed to be associated with the exercise of the function of sight, but they may be merely sympathetic ganglia.

The large *optic thalami* are supposed also to be concerned, in some way, in the sense of vision, but not to the degree indicated by their name; for when they are completely destroyed or removed, the sense of sight and the action of the pupil still remain. Irritation of the optic thalami of one or both sides, is not followed by contraction of the iris; such irritation causes either no signs, or very slight indications, of pain,

and no convulsions. Section of one, is followed by rotatory movements, usually *towards* the opposite side, but, it is said, in the frog, towards the injured side; such movements differ from similar movements, induced by injuries of other parts of the brain, in the fact that the animal continues *standing.* After removal of the cerebral hemispheres, including the corpora striata, the ability to stand and walk remains; but if one optic thalamus be cut away, the animal either exhibits rotatory movements, or is paralysed on the opposite side and falls. (Longet.) It is stated by Schiff, that when the anterior three-fourths of the thalamus are destroyed, the rotation is towards the injured side; whereas, when the posterior fourth is destroyed, it is towards the sound side. By some authorities, the optic thalami, though themselves insensible to direct irritation, are believed to be the great foci of all the sensory nerves, and their grey matter possibly the *common sensorium*, or the nervous centre concerned in common sensation.

The functions of the *corpora striata* are also uncertain. Their removal in rabbits, is said to leave sensation and voluntary motion equally unimpaired; for, though at first passive, after a time, on being irritated, the animal manifests progressive movements of leaping, until it meets with an obstacle, when it again becomes quiet. (Schiff.) Mechanical irritation of these bodies, is said to produce neither pain nor movement. Extravasation of blood into one corpus striatum, causes paralysis of the muscles of the body on the *opposite* side, owing to the decussation of the pyramids, and of the facial muscles usually on the *same* side, though sometimes on the opposite side also; why, is not known. If convulsions occur, they are also usually on the *same* side as the paralysis; in this case, the corpora quadrigemina are also commonly injured. If paralysis happens on one side, and convulsions on the other, there is usually lesion either of the corpus striatum, base of the brain, or cerebral peduncles, and also of the medulla oblongata on the same side, viz. on the side on which the convulsions occur.

As the course of the posterior or afferent fibres of the peduncles, is chiefly through the optic thalami, and the course of the anterior or under set of efferent fibres, is chiefly through the corpora striata, it has commonly been concluded that the *corpora striata* are chiefly concerned in the function of *motion*, and the *optic thalami* in the function of *sensation*; but these views are more or less hypothetical. It has also been suggested, that both the corpora striata and the thalami are sen-

sory ganglia, and have the same relation to the nerves of touch, or common sensation, as the olfactory, optic, auditory, and gustatory ganglia have to their respective nerves. Disease of the optic thalamus, is followed by hemiplegia, i. e. paralysis of both sensation and voluntary motion of one-half of the body, on the opposite side: disease of the corpus striatum has, however, the same effect. It has also been suggested that the optic thalami may be the organic seats of the *emotional* part of our mental nature, in which case, they must act as sensorial centres, recognising the changes which concur in the production of ideas, within the cerebral hemispheres. A still further extension of this view, regards the thalami as the seats of *consciousness of the mental state*, ideational, emotional, rational, and volitional; in this case, just as the sensory nerves and sensory tracts bring impressions from without, to the common sensorium in the optic thalami, and produce sensational consciousness, so it is supposed that the convergent or descending fibres, which pass from the cerebral hemispheres to the thalami, and which Reil named, as we shall see, the *nerves of the internal senses*, may be the paths by which the various actions of the brain itself, may be recognised by the same sensorium, and so cause all the varieties of mental consciousness. (Carpenter.) This ingenious view is, at least, highly suggestive.

From the present state of our knowledge, we may suppose, first, that the grey matter of these large ganglionic masses, the optic thalami, together with the grey matter diffused through the peduncles, pons, medulla oblongata, and spinal cord, constitute the true immediate centres for the reception of all kinds of sensory impressions, with the exception of those of smell,—viz. those of common sensation, the sense of temperature, the tactile sense, perhaps the muscular sense, and the sensations of sight, hearing, and taste. Secondly, it would appear that in other parts of the grey matter, this portion of the great cerebro-spinal axis, from the corpora quadrigemina, corpora striata, and thalami, downwards through the peduncles, pons, medulla oblongata, and spinal cord, we have a *great centre of motorial excitability* (Sharpey), through the agency of which, all the involuntary reflex movements, whether *sensori-motor* or *excito-motor*, are performed.

Whether the large mass of grey matter, above supposed to be engaged in sensation, is itself the *true sensorium*, or actual seat of the *conscious sensation* of bodily conditions, as is commonly believed, or of both bodily and mental states, as sug-

gested by Reil and Carpenter, or whether the impressions produced in it, according to the sense which excites them, must react, in some way, along the radiating fibres which expand from their upper end into the cerebral hemispheres, in order that conscious sensation should be realised, is unknown. It would seem certain, however, that perception or the association of sensations with their causes, ideation or the formation of ideas, memory, and the processes of comparison, combination, and determination of differences, which are implied in reasoning, and, lastly, the resulting volition or will, involve the material operation of the cerebral hemispheres.

Furthermore, whether, in the exercise of this will, in producing voluntary movements, the conducting fibres are prolonged directly downwards from the cerebral hemispheres through the cerebral peduncles, pons, medulla oblongata, and cord, to the motor nerves, or whether the hemispheral fibres themselves end in this great motorial centre, and thus act, not continuously or directly on the motor nerves, but through this automatic centre, so as to impose upon it definite impressions dictated by the will, is not yet fully decided. But the latter view appears supported by anatomical facts and general considerations; and, if this be true, then, even in volitional acts, the actual motor impulse, which immediately excites the muscles, proceeds from the motorial centre, as in the case of any other form of movement excited by an idea or an emotion, by a sensori-motor or instinctive impulse, or by an excito-motor irritation.

The office of the corpora striata, in the exercise of voluntary movements, may therefore be immediate or *direct*, as regards the stimulation of the muscles; but the optic thalami may also concur, in an indirect manner, in those movements, by virtue of their function as sensorial centres. It is known that all muscular movements are accompanied by an internal sense of effort to meet resistance, or by a sense of the condition of the muscles concerned; and this sensation, or *muscular sense*, is more or less necessary for the proper guidance of the movements. Moreover, other sensations, especially that of sight, are commonly associated with certain movements of the body, and are sometimes their only means of guidance. In complete loss of *sensibility* in the legs, even though the power of motion remains, the act of walking is impossible, because the guiding muscular sensations are absent; but sometimes the sight may act as a substitute, enabling feeble locomotive efforts to be

performed, so long as the person can see his limbs. Even where the sensibility of the skin remains, though the muscles are partly paralysed, the same difficulty still occurs in using the limbs, unless they are watched by the eyes. A curious case is on record of a nurse, who had lost the muscular sense in one of the upper limbs, and who could only carry a child by constantly watching that limb; as soon as she turned her eyes from it, the limb would fall helpless to her side. (Duchesne.)

Functions of the Cerebellum.

The cerebellum is not concerned in the exercise of the psychical functions. Neither does it appear, in any way, to be a seat of the function of common or special sensation. Some, however, refer the so-called muscular sense to certain parts of this organ. When pricked or injured, it does not appear to be sensitive, for no sign of pain results from such irritation. Moreover, when it is completely removed, there is no loss either of common or special sensation in the animal. This organ does not appear to be directly concerned in the mental process of volition, since the will still attempts to exercise itself in an animal deprived of its cerebellum; for if the animal be then threatened, it will attempt to avoid the blow, or if it be wounded, it will seize the instrument or hand, to try and prevent itself being injured. Lastly, after the removal of the cerebellum, all the instinctive and simple reflex movements, such as those of swallowing, respiration, and others, continue unimpaired.

Although the will seems unaffected by injury or removal of the cerebellum, the power of executing its various mandates, especially as exhibited in the complicated muscular acts necessary for locomotion, is evidently interfered with. If thrown down, an animal from which this organ has been removed, is unable to rise, though it seems to desire to make the effort; its movements become hurried and irregular, so that there is a want of harmony in its locomotive acts; its equilibrium is no longer maintained, and it appears as if intoxicated. If a section be made through the middle line of the cerebellum, the power of maintaining the equilibrium is instantly lost, and the animal cannot even stand, but may now turn to one side, and then to another.

When the cerebellum of a bird, is gradually cut away, the animal becomes restless, and its movements irregular; and when the whole organ is thus removed, it can no longer walk, leap, or fly, and loses its balance,

being unable to perform any acts requiring combination of muscular movements; yet the reflex movements and sensibility, both appear to remain, as it exhibits no signs of stupor, and endeavours to avoid blows. Laid upon its back, it cannot regain its former attitude, but flutters its wings. When placed on its legs, it staggers and falls, as if intoxicated, endeavouring, however, to retain the standing posture. (Flourens.) In other cases, after gradual removal of the cerebellum, a quadruped animal has been noticed to plant all four of its feet firmly on the ground, and then, on further and further portions of the cerebellum being cut away, it moved slowly or quickly backwards. Various other phenomena have been noticed in pigeons mutilated by removal of the greater portion or the whole of the cerebellum; extension of the legs, with indisposition to flex them, though this could be accomplished by an effort, twisting of the head on the neck, trembling movements of the whole body, vomiting, purgation, and general emaciation, falling of the feathers, and depression of the natural temperature; sensation and will were not destroyed. (Wagner.) According to others, the voluntary movements became, after a few days, almost natural, even though two-thirds of the organ had been removed in pigeons. (Hartwig, Dalton.) On cutting away portions of one hemisphere of the cerebellum, the most remarkable disturbances in the movements of the animal take place; for it revolves as if it were on a spit, turning sometimes to one side, and sometimes to the other. If one hemisphere of the cerebellum be entirely removed, by a section through its peduncles, the animal also revolves in a circle; this may take place sixty times in a minute, and continue for several days. If the other hemisphere be now cut away, the animal no longer performs these curious movements. According to Magendie and Müller, the rotation is towards the injured side, but according to Longet and Lafargue towards the sound side. These differences have been referred to the position and direction of the incisions, but the explanation is not quite satisfactory. The cause of the motion is supposed to be due to the one-sided action of the muscles of the body, being no longer counterbalanced by those of the other side; but another explanation is, that it is caused, not by unbalanced voluntary movements, but by abnormal tonic contractions, excited by the injury, the spine, especially its anterior portion, being twisted, and the animal evidently trying to check the movements. Section of the inferior peduncle of the cerebellum, which connects it with the medulla, causes the animal to bend round to the injured side, from loss of power in the opposite side. Division of the superior peduncles, which pass up to the corpora quadrigemina, whether unilateral or bilateral, has no distinct effect on the movements.

In a few instances which have been met with in the human subject, of congestion or more serious disease of the cerebellum, such as extravasation of blood into one of its peduncles, or pressure from bony or other tumours, backward movements, and continued rotations, have been observed during the life of the patient. It has furthermore been noted that, in an alleged case of absence of the cerebellum, the gait was uncertain, and the intellectual powers weak, although the perceptions and sensations were perfect. (Combette.)

From all these results, it has been inferred that the cerebellum is, in some way, essential to the due regulation or co-ordination of combined or complicated muscular acts, either, according to one view, by a direct governing or co-ordinating power, or, according to another view, because it is itself the seat of the muscular sense, which then conveys impressions to the cerebrum, giving notice, as it were, of the condition of each particular muscle in action, and so furnishing information for the guidance of the cerebral volitional faculty. But as many disturbances of the locomotive function, and especially the peculiar rotatory movements, ensue upon injuries inflicted on other parts of the encephalon; and as these, when produced by sections of the cerebellum, may be counteracted by sections of other parts, it is doubtful how far this latter organ can be regarded as the real governing centre in such co-ordination of the movements. Thus, according to some experiments, when one corpus striatum is cut, the animal runs forwards; and when the optic thalamus is wounded, it turns round and round. (Magendie.) According to other experiments, sections in the fore-part of the brain, cause the animal to turn in a large circle; sections further back, produce rotations in smaller circles, and when one peduncle of the cerebellum is cut, the animal revolves on its own axis. (Schiff.) Even sections of any of the three semicircular canals of the internal ear, in pigeons and rabbits, are also followed by similar rotations (Brown Séquard), and still more remarkable and definite movements have been noticed after such experiments, the animals, according to the particular canal divided, throwing summersaults in definite directions, whenever they attempted to move. (Flourens.) These movements may depend on some disturbance of the function of hearing, but this is not established.

The doctrine, that the cerebellum is the seat of the special faculty named, by the phrenologists, philoprogenitiveness, is not confirmed, though apparently supported by a few isolated cases of disease or injury to this organ. They are opposed by the fact of the slight connection of the cerebellum with the cerebrum, the proper organ of the emotions; by the teachings of comparative anatomy and physiology, as to the relative size of this organ in different animals; by the results of a wider investigation of the phenomena observed in disease in man; and, lastly, by those yielded by experimental researches in animals. Direct stimulation of one side of the cerebellum in guinea-pigs, has been found also to cause rotation, usually towards

the sound side. By others, irritation applied to this part, is said to produce contractions in many muscular organs, even in those of vegetative life, as, for example, in the stomach and cæcum. Vomiting, headache, squinting, affections of the pupil, disturbed vision, and convulsions, accompany morbid irritation of this organ, with evidences of disturbed movements, said to be due to interference with the muscular sense. (Lussana.) Inflammation of its membranes is unaccompanied by delirium; and, in cases of gradual softening of this organ, the intellect may remain unimpaired, even though it be almost entirely destroyed. Chronic disease of the cerebellum, however, is sometimes accompanied by unsteadiness in walking, without any symptoms of paralysis; in a few cases of disease of both hemispheres of this organ, backward movements have been noticed, and affections of one peduncle have been accompanied, in a few instances, by rotatory movements towards the diseased side.

Our general knowledge of the functions of the cerebellum being so scanty, it will be no matter of surprise that we are entirely ignorant of the relative importance and office of its several parts, viz. of the hemispheres with their lobes, the upper and lower vermiform processes, and the plicated sacs of grey matter in its interior, known as the corpora dentata.

The direct connection of the cerebellum with the cerebrum, is limited to the small superior peduncles, whilst it is much more extensively connected with the lateral columns of the spinal cord, by its large inferior peduncles; hence its anatomical connections seem to favour the views concerning its influence in the regulation and co-ordination of the muscular movements, rather than the supposition that it can exercise any important mental functions. Finally, it has been remarked that the gradually increased development of the cerebellum in the series of vertebrate creatures, from the fish up to man, coincides generally, with a greater and greater degree of complexity in the movements which they can perform, involving sometimes almost all the muscles of the body, and necessitating more extensive and perfect co-ordinating power. In what way this supposed faculty is exercised, is unknown. On the supposition that it co-ordinates the muscular movements, by being the seat of the *muscular sense*, some have suggested, that the impressions originating in the muscles, reach it through the restiform bodies, which are highly sensitive; moreover, it has been surmised, that the corpora dentata are the seat of this muscular

sense, and that the hemispheres react upon impressions conveyed to them from those bodies. Yet it is difficult to suppose that the muscular sense, which appears to be only a modification of common sensation, has a special ganglionic centre. It has also been suggested, that the corpora dentata may be the seat of the muscular sense, and the hemispheres, of philoprogenitiveness. (Dunn.) It must be confessed that the functions of this organ, are but imperfectly ascertained.

Functions of the Cerebrum.

The investigation of the special functions of this important part of the encephalon, is surrounded by great difficulties. We have already spoken of the large masses of grey matter situated deeply within the cerebrum, viz. the corpora striata and optic thalami, and the part they are supposed to play in the functions of sensation, and in the government of motion. But, in the superficial grey matter of the cerebral hemispheres, we recognise the anatomical organ which is physiologically concerned in the exercise of the faculties of *conscious attention*, *perception*, *ideation*, or the formation of *ideas*, probably also in *emotion*, and certainly in the operations of *memory*, *reason*, *judgment*, and *will*. The hemispheres proper, appear, indeed, to be supplementary organs, superadded to the great nervous sensori-motor axis, not essential to it or to life, but acted upon by, and reacting through it. Their anatomical connections entirely favour this view.

The chief facts, in support of the opinion, that the brain is the corporeal organ, through which *mental* manifestations occur, are these: first, concussion, from severe blows, suspends all consciousness, and, with it, the higher mental operations; pressure, whether produced by a depressed portion of the cranium, by effusion of blood into its interior, or by effusions of a serous character, equally interferes with these functions; the effects of pressure have even been made evident in the case of persons whose head has been trephined, by the temporary application of the finger to the exposed membranes of the brain; moreover, inflammation of the membranes covering the surface of the hemispheres, or of their cortical substance, usually causes delirium; in fatal cases of acute mania, the cortical substance is generally dark red; lastly, chronic destructive diseases of certain parts of the cerebral hemispheres, have been shown to be accompanied by impair-

ment or loss of the mental faculties. Secondly, the relative size of the cerebral hemispheres, or, more accurately speaking, the relative quantity of the grey matter in them, presents a certain general correspondence with the mental endowments of the individual, the variety, and the species; of this, we shall give evidence in speaking of the brains of animals. The relative development of the several parts or lobes of the cerebrum, must here, however, be taken into account, and so likewise must the temperament of the individual, whether this be slow or quick. Thirdly, in cases of imbecility or absolute idiocy, the cerebral hemispheres exhibit the most remarkable defect in development of any part of the encephalon, although, as has been recently shown by myself, the corpora striata and optic thalami are involved in this deficiency, and even the cerebellum is also somewhat affected. Lastly, in no other part of the body, and in no other organ, is there such a corresponding development or deficiency, in proportion to the mental power, in both different men and in different animals, as in the hemispheres of the cerebrum.

Attempts were made, long before the more systematic teachings of phrenology, to locate certain faculties of the mind, in certain portions of the cerebrum. Thus, the intellect was supposed to be placed in the anterior region, the emotions or sentiments in the middle, and the instinctive feelings in the posterior part. By some, the memory also was located in the hinder part of the brain. The phrenologist teaches, proably correctly, that *memory* is exercised through every portion of the cerebral hemispheres; whilst he locates one powerful *instinct*, *philoprogenitiveness*, in the cerebellum; the lower *propensities* of animal nature, at the base and back part of the cerebrum; the *sentiments*, in the upper and middle part; the *observing* faculties, with the faculties of language and music, in the lower part and sides of the frontal region; and the so-called *purely intellectual* faculties of comparison and causality, in the upper frontal region. The chief argument in favour of any system of phrenology—for several have been proposed—is, that the science has been deduced from the actual observation of nature, that is, from a comparison, in very numerous instances, of the form of the skull, which is taken to represent the form of the cerebrum beneath it, with the propensities, moral feelings, and character, the acquirements, and endowments, of the individual. There is nothing irrational in the attempt to discover special organs in the

brain for the performance of special functions of the mind; but the task is not so easy as Gall and his school have imagined. To their systems and method it has, indeed, been objected, that the instances of correspondence with the craniographic schemes projected by Gall and Spurzheim, and since modified and expanded by their followers, have been mainly collected by partisans of craniology or phrenology; that no systematic investigations have been undertaken, by other and independent observers, to test the actual frequency of those correspondences, or to detect any failures of such correspondence; that, in many instances, however, which have been noted, the most complete discrepancy has existed between the local development of the cranium, and the activity of the faculties or powers supposed to be exercised through the agency of the subjacent parts of the brain; and, lastly, that in reference to any given faculty, one such well-marked case of discrepancy, is sufficient to shake the system, as regards that faculty, to its foundation. It has, furthermore, not escaped the attention of the unbiassed physiologist, that, in spite of a general resemblance between the form of the cranium and that of the cerebrum beneath it, there are many difficulties, such as the relative projection of the frontal, parietal, and occipital eminences, the greater or less thickness of the cranium, and the variable size of the frontal sinuses, in different individuals, which render it almost, if not quite impossible, to determine accurately, degrees of local development of the parts beneath. Moreover, it has been shown by anatomists, that certain points or lines on the surface of the hemispheres—for example, the fissure of Rolando, and the convolutions in front of and behind it—do not invariably correspond with the same parts or lines of the cranial walls; but that, by excess or diminution of development, in these or in neighbouring parts, they may shift their position backwards or forwards beneath the skull. It has also to be noted, that the convoluted grey cortical substance of the hemispheres, the supposed physiological seat of any force or faculty, which these parts of the cerebrum may exert, is not limited to that part of the cranial surface which is open to observation, nor, indeed, to the inner surface of the cranium at all; for it extends on each hemisphere, to the frontal and temporal fossæ, at the base of the skull, and even to the upper surface of the tentorium; and it likewise sinks deeply into the longitudinal fissure, quite away from the skull itself, and also into the Sylvian fissure, at the bottom of which, it forms the central

lobe, or island of Reil, a part completely concealed between the overlapping edges of the frontal and parietal lobes. Lastly, no external cranioscopical observations can determine the relative complexity of the cerebral surfaces, nor the relative thickness of the grey matter. These facts, together with the utter absence of any coincidence between the boundaries of the convolutions and the craniographical mapping out of the so-called *organs* of the phrenologist, have led the most learned and influential anatomists and physiologists to demur to the system originated by Gall and Spurzheim. Nor is the catalogue of presumably *distinct mental* faculties, enumerated by the phrenologists, more satisfactory to the modern school of metaphysicians. Hence, whether the subject be regarded from a physiological or from a metaphysical point of view, although it may be true, yet not established, that different parts of the cerebral hemispheres exercise certain special mental functions, still it is by no means determined, either what those distinct or primal faculties or powers may be, much less the locality or organs, in or by which they are actively exercised in the body.

The first noteworthy observations, made in cases of disease of the cerebral hemispheres, tending towards a determination of the locality of any particular faculty, have been those collected by M. Broca, in reference to the faculty of *language*, which, according to him, has been noticed to have been lost in several adult persons, who, after death from paralysis, were found to have had *softening* of the upper and posterior part of the frontal lobe, in front of the fissure of Rolando. It is a singular, and hitherto quite unexplained fact, that, in these cases, the injured part was always on the left side of the cerebrum; and Dr. Hughlings Jackson has since shown that this is almost an invariable rule. Much further observation is needed to clear up this question, and it is yet premature to conclude that the organ of language is situated in the locality found in these cases to be diseased.

Experiments made upon animals, with the view of determining the special functions of the cerebral hemispheres, throw only a most general light upon this subject. The first great and fundamental fact to be noted is, that the cortical substance of the cerebral hemispheres can hardly be the seat of sensation, for it is itself insensible. Animals exhibit no signs whatever of pain, and no muscular contractions in either the muscles of animal or vegetative life, when the hemispheres are superficially pricked, pinched, or cut; and even in the

human subject, injury to this part of the brain, or removal of portions which protrude after accidents to the head, does not cause local suffering, even though the consciousness be perfect. Neither does injury to these parts, inflicted purposely on animals, or accidentally on man, cause any convulsive motion. Nevertheless, though itself insensible, this cortical hemispheral matter is believed to be the place where sensations become perceived, *i. e.* referred to their external causes, where attention is exercised, where ideas are formed, and emotions are excited; where memory retains its impressions, and where the will originates. For in animals, when the hemispheres are mutilated, the cerebral functions are disturbed; and when they are removed, those functions are suspended or destroyed. Thus, when one hemisphere is removed, there is produced temporary feebleness of the opposite side, with a permanent blindness in the opposite eye. After partial removal of both hemispheres, stupor is produced; but there soon return evidences of sensation, and of much muscular power. But when both cerebral hemispheres are completely removed, a kind of stupor exists; the animal remains in one attitude, and seems incapable of originating any independent movement. It still, however, retains the power of reaction, or reflex motion, on the application of external stimuli; for when the cerebral hemispheres of a pigeon are removed, leaving the optic thalami and optic lobes, besides the reflex contraction of the iris and closure of the eyelid, on the approach of a lighted candle, the bird follows the light with the head; so likewise, when the brain of a rabbit, including the optic thalami, is removed, it will withdraw its leg when it is pricked, and cry if its whiskers be pulled. But these latter movements are not positive evidence even of conscious sensation, much less of perception and will; they are, almost certainly, purely reflex, performed on the same principle as the simpler reflex movements, but possessing a more complex character; they are probably entirely unaccompanied by perception, and even if they be associated with any sensation, this is probably of a very feeble or obscure kind. Even the pigeon, when deprived of the hemispheres only, as above mentioned, though it may see objects, runs up against them, apparently from loss of perception and memory.

The cerebral hemispheres have been removed in birds, chiefly in pigeons (Longet), which, by artificial feeding, have then been kept alive for months. Birds so treated, sit still, as if asleep, with the neck re-

tracted, the wings closed, and resting on both feet. When pushed, or when the foot is pinched, they seem to awake, to shake their body and feathers, open the eyes, advance a step forwards, and then relapse into their state of slumber. If dropped in the air, they spread out their wings, and even fly up, but strike against objects, and soon fall to the ground, from which they do not attempt to rise again. Sometimes they wake spontaneously, and prune their feathers. The eyes are still sensible to light, the pupils contracting; the eyelids are not closed at the approach of a candle, but some signs of uneasiness are manifested, and the bird follows the light by movements of the head. In a case observed by Malacorps, the pigeon was not affected by sudden exposure to strong light; but it appeared to seek out the light parts of a dark place; and was readily roused by slight noises. By Longet, however, noises were found to produce no effect, but, when very loud, caused, at the most, the animal to start; but this might be simply due to mechanical shock. If the toes be touched, the foot is drawn away; and on repeating the irritation, it may be withdrawn under the wing, and the bird remain standing on one foot without loss of balance; if now, the other foot be irritated, it withdraws this, and puts out the opposite one. If ammonia be held to the nose, the head is violently shaken, and the bill is scratched with the foot. The bird can no longer pick its food; when this is placed in the bill, it remains there; but when put on the back of the tongue, it is swallowed.

Similar experiments have been made on quadrupeds, with corresponding results, dogs no longer recognising their master. All the phenomena seem to show, that not only the movements, but even combinations of movements to certain ends, occur after removal of the cerebrum; the state of the animals, however, is like that of dreaming, in which the acts are not accompanied by distinct perceptions of external objects, though by an imperfect consciousness. As regards sensory impressions, their condition is precisely similar, indicating a feeble or imperfect persistence of conscious sensation. This result sufficiently proves that the cerebral hemispheres are not the sole seats of consciousness, if, indeed, they are at all concerned in mere sensation. The loss of conscious power in such experiments, may not depend on any of it being, as it were, resident in the hemispheres, and so lost with them, but on the shock to the real sensory ganglia, caused by opening the cranium, and by exposure of these parts, loss of blood, and general depression of the remaining vital power. The movements of the animals are probably reflex, but of a higher kind than those performed through the cord and medulla: thus, a decapitated bird cannot, like the bird from which the cerebrum has been removed, stand on one foot, nor is the foot withdrawn beneath the wing, but it exhibits only convulsive resisting movements; it can neither walk, fly, nor prune its feathers, which are co-ordinated acts, governed by the cerebellum, and by the pons and other central parts at the base of the cerebrum.

In man and animals deformed by monstrosity, in which the cerebral hemispheres are especially defective, or even absent, reflex phenomena similar to those already mentioned (p. 371), are observed; for example, they may suck, swallow, and even cry, but they present no manifestations of any perceptive or

other mental quality. That they may have sensation in a feeble degree is probable.

Disease of *one* hemisphere in man, so extensive as almost to destroy it, has occurred without any disturbance or diminution of the mental faculties; but when both hemispheres are seriously implicated, such phenomena are always manifested. Slow distension of the hemispheres, by an accumulation of cerebro-spinal fluid in the ventricles of the brain, does not much impair the action of this organ. All sudden injuries, even if slight, act severely as shocks; but slow suppuration, for example, has less effect. Inflammation and chronic disease of the grey or cortical matter, are usually accompanied with excitement or lowering of the mental faculties, whilst changes in the white or medullary substance, more frequently cause torpor, and loss of voluntary control over the muscles.

Of the cerebral hemispheres, it may therefore be said, that, by physiological experiment, we have proof that sensations may perhaps be *consciously felt* without them, but that they are certainly concerned in the *perception* of sensations, and in the origination of the volitional motorial stimulus or will. It would also seem, on general grounds, that their integrity is essential to the manifestation of that chain of mental acts which may be said to intervene between mere perception and the exercise of the will—that is to say, ideation, memory, association, and the reasoning processes. As to the emotions, the supposition of their association with some action of the cerebral hemispheres, rests only on general probability.

The hemispheres appear, however, to be the medium by which, through the channels of special and common sensation, the mind is brought into relation with the outer world, and reacts, through the motor paths, consciously and purposively upon it. This conscious action, which is, in a certain sense, reflex, is intelligence in action, and, as a rule, is proportionate to the size of the cerebrum. It gradually diminishes in the descending animal scale, in proportion to the relative decrease of the size and complexity of the brain in comparison with the size of the body. The proportionate weight of the cerebrum is not here the only fact to be considered; but also, first, the presence and degree of development of the convolutions, which serve to increase the extent of the grey matter, and, secondly, the thickness of the cortical grey substance which follows the convolutions. The relatively larger number of the

transverse commissural fibres, in the brains of the higher animals, and especially of man, is probably also one element of their superiority. The uses of these commissures are not known, further than that they must serve to associate physiologically, the opposite halves of the brain. Deficiency of the corpus callosum has been found to be accompanied with want of intellectual power.

From the anatomical fact already mentioned, that the fibres, ascending from the cord and medulla oblongata along the peduncles of the cerebrum, pass no higher than the grey substance of the optic thalami and corpora striata, which bodies are connected with the grey matter of the cerebral hemispheres by a distinct system of ascending or radiating fibres, and from other considerations, it is probable that the only path of communication between the cerebrum and the outer world, is through that great sensori-motor nervous centre, which is composed of the large masses of grey matter found in the base of the brain, cerebral peduncles, pons Varolii, and in the medulla oblongata, and spinal cord. Even the volitional movements, though dictated by impulses originating in the cerebral hemispheres, are probably excited by stimuli proceeding directly from the sensori-motor nervous axis. In accordance with this view, the psychical acts, consequent on sensation, have been thus localized: a sensory impression, reaching the conscious sensorium or sensory portion of the sensori-motor apparatus, produces therein a sensation; this sensation, exciting in its turn the cerebral hemispheres, is supposed there to give rise to an idea; the idea, if associated with a feeling of pleasure or pain, becomes an emotion; and such ideas and emotions, when subjected to the intelligence or reason, lead to volitional determinations, or acts of will, which may either produce or restrain particular movements, or may govern and direct the processes of thought. (Carpenter.) The exercise of the will on the voluntary muscles, is also believed, as already mentioned, to be indirect—that is, by actions originating in the hemispheres, and operating on the sensori-motor ganglionic apparatus, at and below, the base of the cerebrum, which apparatus then excites the motor nerves. Admitting the correctness of these views, it might be said that the fibres which are known to connect the optic thalami with the cerebral grey matter or cortical substance, are ascending or radiating fibres; whilst those which connect the corpora striata with the same parts, are descending or convergent,

though anatomically, all may be considered as either radiating or convergent. The term "*nerves of the internal senses*," applied to the white fibres of the hemispheres, by Reil, expresses the general notion that they are concerned in offices of conduction related to the exercise of the emotional and intellectual operations. In further proof of this, it has been remarked, that the will determines only the performance of a given act, or the accomplishment of a certain end or purpose, not the chain of individual and combined movements necessary to arrive at such results. The mind is ignorant of the anatomical positions and connections of the muscles which it employs, or even of their existence; and this is equally true, whether an act be complex and effected by many muscles, like one of the movements of the upper limb, or simple, and performed by a single muscle, as occurs in raising the upper eyelid, or turning the eyeball to one side. In either case, the act is performed by willing a result, not by willing the muscular contraction. The regulation of the muscles of the larynx, for the production of the various vocal tones, is also similarly accomplished by the will, not directed to the laryngeal muscles, but to the purpose of producing a definite note, guided by the sense of hearing. The general fact, that most of the automatic movements performed by muscles of animal life, such as those of laughing, yawning, coughing, sneezing, winking, and so forth, can be imitated voluntarily, also favours the conclusion, that the motor apparatus *immediately* exciting the motor nerves is, in the two cases, identical. There are undoubtedly, indeed, voluntary movements, which may become, by the force of habit, automatic; and many ordinarily automatic movements may be suggested through ideas, or imitated by the action of the will; both sets of facts would therefore favour the conclusion that the nervous apparatus immediately directing the movements of the muscles, is the same, whether the act itself be automatic, ideational, or volitional. Thus, coughing and sneezing may be imitated voluntarily; yawning, by seeing others yawn; the convulsions of hydrophobia, by looking at bright objects suggesting the idea of water, or even by hearing water spoken of; and, lastly, vomiting may occur from the remembrance of nauseous tastes, or of the disagreeable feelings of sea-sickness. On the other hand, the action of walking, or even those more complex movements which are performed in playing on musical instruments, may, as already mentioned, become habitual or automatic.

Psychical Functions of the Nervous System.—Mental Faculties of Man.

Whether the mind be regarded as a single entity, distinct from the body, or whether the psychical manifestations or mental processes be viewed as the mere result of changes in the nervous substance of the cerebrum, it is certain that the brain is the corporeal organ through which those functions are performed; for, as we have seen, in order to give rise to those phenomena, which we are accustomed to designate mental, either external or internal influences or stimuli must operate upon, and excite, that organ. Moreover, disturbances in its condition, and interruption of its functions, are attended with essential disturbances in, and cessation of, the psychical acts.

The fact, already mentioned, that, in the ascending scale of animals, the brain is gradually more developed as the mental powers increase, justifies the inference, that the superior mental endowments of man, as compared with those of animals, are related to those parts of the nervous system, the extraordinary development of which, distinguishes man structurally from animals.

The impressions transmitted through the sensory organs and their sensory nerves, to those parts of the brain, whichever they may be, which constitute the *sensorium*, excite the *consciousness*, and produce *sensation*. Sensation is the simplest psychical process, and sensations are, so to speak, the sources of all further mental activity. For the occurrence of temporary sensations, excited from without or from within, mere consciousness alone is sufficient; but when such sensations are to be rendered useful, as the subjects of succeeding mental operations, an internal active process is essential, viz., that of *attention*. Without this condition, impressions may sometimes be produced, and yet their effects on the consciousness may remain completely unnoticed. The sensory impressions, when realised through the attention, probably by aid of some simultaneous changes in the cerebral hemispheres, are then, by the act of *perception*, a far higher mental process, referred to their proper external causes, and thus successions of so-called *ideas* are formed. The formation of such ideas has been named *ideation*. Now, an idea may be transitory; but, on the other hand, it may also leave behind, probably in connec-

tion with some deeper changes in the nervous substance, a more permanent impression, and, by some occasional cause, by association, or, after practice, by the force of the will, it may again be called into existence, and this process is aptly named *recollection*, and the faculty by which it is accomplished, *memory*. These ideas constitute the materials of further *thought*, i. e., of *association*, *comparison*, and *combination*; and hence arise, amongst other notions, those of the distinction between the body or corporeal frame and the outer world, or what are sometimes erroneously designated the *subject* and the *object*; also such notions as repetition, mass, and the sequence of events.

The higher animals are also capable of forming such ideas, and can compare and combine them in the act of *thinking*, so as to attain certain notions, and to acquire a given amount of knowledge and experience. But the sphere of this knowledge is limited, the ideas on which it is based are simple, and the notions formed are what are termed *concrete*; whilst the actions which follow, still refer merely to the conditions of their individual life, such as the obtaining of food, the avoidance of danger, pain, or injury, and the satisfaction of impulses which tend towards the maintenance of the species. By means of education and special training, a wider range of ideas and notions —still, however, of the concrete form—may, with time and labour, be imparted to, or aroused in, certain animals; but these are all extinguished with the individual, and are lost for the species. At the same time, certain special instincts, capable of cultivation, which are in no way due to processes of reason, and are certainly not the *results of teaching*, but rather *of primary impulses*, originating in the organisation and nature of the individual animals, may be trained, and strengthened, and so transmitted, in the form of *habits* to the young, as is seen in the case of certain breeds of dogs.

In the human mind, however, besides the perception of simple concrete ideas, and the formation of concrete notions, *abstract* ideas arise by the further mental process called abstraction, and sometimes *conception*. Not merely is the outer world perceived by man, and recognised as an existence external to himself, consisting of objects and forces, differing from each other, and having certain mutual relations; but he can form abstract conceptions concerning himself, even concerning his mind, as distinguished from his body, thus reaching to the real *subjective* and *objective* distinctions of

the metaphysician; for, in the estimation of the latter, even the body is objective to the real subjective 'ego,' or 'self.' He can likewise form similar conceptions concerning the outer world, the properties of objects, the causes of those properties, the nature of matter and force, the laws of the universe, and so forth. Moreover, he can proceed to reflect and reason upon these abstract ideas and notions, as yet further and independent objects of thought. The higher animals, then, have intelligence, and *understand*; but man alone, is gifted with the power of forming abstract conceptions, and again considering these; in other words, he alone possesses the attributes of *pure reason*. Thus, an animal, as already said, may attain to a notion of what is hot or cold, pleasant to the taste, or painful to the touch, of the repetitions of objects, of mass, and sequence, but it does not, like man, rise to a conception of *temperature*, *taste*, or *pain*, of *number*, *quantity*, *space*, and *causation*, apart from facts, and from its concrete ideas and notions of experience; but, beyond this, man is enabled, by his faculty of *abstraction*, to form the higher abstract ideas, and purely psychical notions or conceptions; proceeding step by step, till he arrives at notions, dim it may be, of an infinite past, an infinite future, a first and sustaining cause, a Creation and a Creator, and of the inevitable relations of his own nature to the great plan of Providence.

The *instincts* of animals are *innate impulses*, manifested in purposive actions, dependent, not on imitation, or habit, or reason, but on the very nature and *organisation* of the animal itself, which is endowed with certain desires and fears, and acts so as to satisfy the former, and allay the latter. As a rule, these are perfect and uniform in all individuals, and practically immutable in the species, are uncontrolled by reason, or by an abstract desire for advancement, and constitute, indeed, the preponderating motives, or governing causes, of the actions of animals, even of the highest mammalia. In some of them, however, there is seen, even in the wild state, occasional evidence of cunning, which implies a certain exercise of the understanding, and a sagacity which can only be the result of intelligence; but the end to be gained, is still the gratification of some animal want. Man, likewise, is actuated primarily by his instincts in all he does; these are radical parts of his mental constitution. Many men, both in civilized and uncivilized communities, remain, like the animals, mere creatures of instinct; and amongst all men, these

common instincts form the basis of their general life; the instinct of self-preservation, and those impulses which lie at the foundation of society and of the domestic relations, are the most powerful. But these and the subordinate instincts and desires, are variable in *degree* in different men, and they are controllable by *reason*, and by *will.* Hunger and love are the momenta of human action; but man need not steal, nor yield to the suggestions of passion. Hence his liberty, his free-will, and his responsibility. As consequences of this freedom of will, to do or not to do, man's mental and moral nature is more plastic, more expansible, and more improveable than that of animals. Animals may be trained and become obedient to man, probably from fear of punishment, or expectation of reward, occasionally perhaps from emulation; they may be taught to do this, and not to do that; but they can have no abstract conception of right or wrong. Man, however, undoubtedly may act irrespectively of personal motives, without fear of consequences, regardless of applause or gain, and frequently at the cost of self. Animals obey a master, but even then, without a notion of obedience in the abstract; but man obeys his judgment, knows what is obedience, and, moreover, has the abstract notion of *rectitude.*

In the contemplaticn of *abstract right* and *wrong*, as applied to his own actions, man feels his imperfections, but also perceives his own capacity for advancement and improvement, both physical, intellectual, and moral. In the interests of himself and of his race, he desires this advancement. By his intellectual powers, he not only inquires into causes and effects, in natural phenomena, but, by the application of his knowledge, through force of will, ending in invention, he renders the knowledge he has so obtained, useful to his fellow man, and to his posterity. Moreover, he desires and loves knowledge for its own sake, or for the pleasure it affords him, as a means of insight into the works and phenomena of Nature. In the sphere of morals, the desire for improvement is also a characteristic of Humanity, considered in the abstract, though it may be lost in the individual man; it has been even regarded as a Human *instinct.* But the standard of perfection conceivable by man, is felt to be beyond his actual reach; and, if all instincts have an object, this also must have its aim, to be attained, if not in a material, in a spiritual state of existence.

General Summary of the Functions of the Cerebro-Spinal Nervous System.

Having now described, in detail, the offices of the several parts of the cerebro-spinal nervous system, and having stated the experimental and other facts, on which our yet imperfect knowledge of those functions is based, it may be useful to point out, by way of general summary, the parts concerned in the exercise of each of those leading functions.

Psychical faculties.—There is reason to believe, that all the mental phenomena, properly so called,—commencing with perception, and passing on to ideation, memory, reasoning, and volition, also including perhaps the emotions, and, if we can regard it as a distinct human faculty, the power of employing spoken or written signs or symbols, to express ideas and notions, or the faculty of language,—are exercised or manifested fundamentally, through the agency of the cerebral hemispheres, especially through the action of the grey matter covering those hemispheres. All these faculties are injured or lost, from sections, injuries, diseases, or destruction of those parts.

Sensation.—Mere sensation, without the distinctness and memory associated with the higher faculties of attention, perception, and ideation, appears to have, for its seats or centres, the olfactory lobes and some of the grey masses at the base of the brain, at all events, the optic thalami, and corpora quadrigemina, and also some of the grey matter in the cerebral peduncles, the pons, and the back part of the medulla oblongata. The olfactory lobes appear to be the centres of the special sense of smell. The visual sense has apparently for its centres, the corpora quadrigemina with the back part of the optic thalami; the office of the corpora geniculata, in regard to vision, is unknown. The sense of taste resides in the grey matter of the upper part of the back of the medulla oblongata, and the sense of hearing, still lower down, in the same part of the great nervous axis. General or common sensibility is probably diffused through all the grey matter from the base of the cerebrum downwards, at least to the lower part of the medulla oblongata. Whether it should be regarded as extending also down the spinal cord, whilst this remains in connection with the encephalon (an opinion entertained, amongst others, by Pflüger) may well be doubted, if not denied; for, owing to the condition of things, it cannot be

proved, and the retention of excito-motor power, with the cessation of sensibility, which necessarily follow the severance of the cord are quite explicable on the hypothesis that it is merely a conductor of sensory impressions upwards to the encephalon. As to the special seats or centres of the tactile sense, of the sense of temperature, of the common sensibility to pain, and of the muscular sense, the latter of which, however, is supposed by some, to be seated in the cerebellum, and as to the seats of those other and more vague sensations belonging to the vegetative or nutritive system, such as hunger, thirst, nausea, want of breath, &c., we are quite ignorant of their exact locality, although there may be special centres devoted to each or to some of them.

Voluntary motion.—The seats, or centres, in which the volitional motorial stimulus originates, are certainly the cerebral hemispheres; for the will is completely annihilated, when these are removed, or when their integrity, or power of action, is otherwise interfered with. Whilst, however, the will to act arises in the cerebrum, the co-ordination of the various movements of the body, seems to require for its accomplishment, the direct or indirect co-operation of the cerebellum.

Involuntary motion.—Involuntary motion includes movements suggested by ideas, *ideo-motor* (Carpenter), *emotional* movements, *instinctive*, or *sensori-motor* movements, which are reflex movements of a more general and more highly co-ordinate character, and are accompanied by sensation; and lastly, the more *simple reflex* or *excito-motor* movements, which are not necessarily accompanied by sensation, and which include some governed by the spinal cord, and others regulated, as we have hereafter to describe, by the action of the sympathetic system.

The *ideo-motor*, or ideational movements, such as those of laughter, or sadness, produced by ideas passing through the mind, must have their organic centres in the cerebral hemispheres; so, too, the co-ordinated movements are performed under the influence of ideas arising in the mind, during reverie, dreaming, and somnambulism, when consciousness is absent.

The *emotional* movements, such as the sobbing of grief, or the smile of joy, must likewise have the cerebral hemispheres as their centres of origin, if we regard those hemispheres as the seats of the emotional faculties themselves; and not, as some imagine, the great ganglia at the base of the brain.

The *instinctive* or *sensori-motor* movements, such as those of sucking, clinging, or attempting to retain the balance, winking the eyes, and many others, manifested even in the new-born infant, appear to have their seat in the great centre of sensorial and motorial excitability, extending from the corpora striata, optic thalami, and corpora quadrigemina, through the cerebral peduncles, the pons and medulla, and down through the whole length of the spinal cord; for such movements continue after the cerebral hemispheres have been removed, in animals, and occur in the human infant, in cases of monstrosity, in which the upper part of the hemispheres is wanting. These instinctive movements merely differ from the ordinary reflex acts, in being associated with sensation, in being more complex, and in involving a greater extent of the nervous and muscular apparatus.

The simpler *reflex*, or *excito-motor* acts are also performed through the agency of the same motorial grey centre, extending from the corpora quadrigemina down to the lower end of the cord; but they involve, in their performance, smaller portions of that long chain of grey nervous substance, and do not necessarily excite its sensorial portions.

Of the reflex movements generally, whether excito-motor or sensori-motor, some are concerned in regulating the functions of the organs of the *senses*, such as those which govern the condition of the iris, the ciliary muscle, and the muscles of the tympanum. The *preservative* reflex movements are illustrated by the winking of the eyelids to moisten the eyeballs, and relieve the retinæ temporarily from the effects of light; and by the acts of sneezing excited by impressions on the retina, or on the nasal mucous membrane, for the expulsion of noxious matter from the nose, of coughing to expel foreign bodies, or mucus, from the larynx, or air tubes, and of vomiting, whether induced by disagreeable odours, tastes, or offending matters in the stomach, or even by sea-sickness. The shutting of the eyelids and the closure of the glottis, or aperture leading into the air-passages, for the prevention of foreign bodies entering the eye, or of poisonous gases entering the lungs—are further illustrations of protective or conservative reflex acts.

The act of deglutition, and the respiratory movements, are also reflex; and so are the irregular or spasmodic inspiratory movements produced by sudden application of cold water to the skin. Still more simple spinal reflex movements

are, the snatching away of the hand, or the sudden lifting up of the feet, from unexpected causes of irritation. Many other illustrations may also be adduced of such reflex movements; such are, for example,—belonging to muscles of *animal* life—the starting on hearing sudden, loud noises, probably also the movements of walking in sleep, or in the state of somnambulism, though these imply also a great power of co-ordination; even, to a certain degree, the ordinary unconscious walk of persons absorbed in thought; the performance of complex, though habitual, movements on musical instruments; other habitual, and all the instinctive movements of men and animals; and, as the results of morbid or exalted action, the rolling of the eyeball and spasm of the eyelids, in irritable states of the retina, and the spasmodic movements of hydrophobia, hysteria, chorea, epilepsy, and tetanus. In the sphere of *vegetative* life, may further be mentioned, the action of the cardiac, and perhaps of the pyloric, circular fibres of the stomach, and certain general movements of the stomach and intestines; yawning, and sighing, as the results of fatigue, or of some oppression of the respiratory organs; and even laughter, when caused by tickling, and not by ludicrous ideas, or pleasurable emotions.

The office of the great excitable nervous centre of the reflex actions, may be said generally to be, to excite and regulate all the muscular movements necessary for the continuance of organic or vegetative life. It has been well remarked that it never sleeps. (Marshall Hall.) Whilst various movements, immediately necessary for the preservation of the organs, or of life itself, are thus performed, those which, like the prehension of food and others, are only more remotely necessary, have more or less of reason and will associated with them. In this latter case, the afferent impressions from without, ascend to the cerebrum, and operate by inducing ideas, emotions, reasoning processes, and volition; and this is the ordinary case with man. If, however, their ascent to the cerebrum be arrested by sleep, coma, the influence of narcotics, or the actual destruction of the parts by disease; or even if the powers of the attention be not directed to them, then purely sensori-motor actions ensue, as is the normal case, in those of the lower animals which possess no higher nervous centres than these sensory ganglia. Extremely powerful stimulation of these parts in man, is also followed by sensori-motor acts, even when the cerebral functions are in a state of perfect activity. The actions of infants generally exhibit the same absence of cere-

bral government, being mostly sensori-motor, as, for example, the act of sucking. Lastly, in idiots, the predominance of the sensori-motor over the rational acts, is very obvious.

The particular parts of the great excitable centre, which are called into action in these several reflex movements, may be inferred, from the attachments of the afferent and efferent nerves engaged; that is to say, of the afferent nerves which receive the external stimulus, and convey its effects to the nervous centre, and of the efferent nerves which supply the muscles thrown into action. These details will be referred to, under the description of the functions of the several organs concerned in these reflex movements.

The involuntary reflex movements, whether complicated or simple in their nature, require no previous education or instruction for their proper performance; and thus their due occurrence is provided for, independently of any effort of the intelligence and the will, so that the mind is free to perform its own workings, whilst the care of the body is entrusted to other powers resident in the system, which induce no exhaustion of the volitional power. Nevertheless, some of these reflex movements, whether ideational, emotional, instinctive, or simply preservative, may be controlled by the will, and may also be imitated under the influence of the will; for we may stop laughter or sobbing, or arrest for a time the respiratory movement; or, on the other hand, we may imitate or perform these movements through voluntary efforts. A certain number of these movements, however, are placed entirely beyond the direct control of the will, as the movements of the iris, and the last stage of deglutition.

The higher reflex movements, viz., the ideational and emotional, are ordinarily accompanied by consciousness and sensation; but ideas occurring in dreaming, and like states of unconsciousness, also give rise to similar movements, which therefore furnish examples of cerebral reflex acts without conscious sensation. The other reflex movements may also be accompanied by sensation, as, for example, the act of deglutition, the acts of coughing and sneezing, and that of snatching away the hand from a hot body. But the lower reflex movements, whether complex or simple, are not necessarily attended with conscious sensation, and are certainly quite independent of it, as we see in the movements of the iris; also in instances of paralysis of the lower limbs, in which the reflex movements still continue; and likewise in the performance of

deglutition and of respiration, in a state of profound coma, and of respiration under the influence of chloroform, or in the condition of sleep, both of which have the effect of perfectly suspending conscious sensation. This independence of sensation, on the part of the reflex acts, necessarily diminishes the fatigue that would be attendant upon their performance, if they were incessantly brought before the mind, as subjects of the faculty of attention.

There are certain movements, performed by man and animals, which are known as *automatic*; examples of these are met with not only in the involuntary, but also, in the voluntary muscular organs. The rhythmic movements of the heart, are of this kind, and also those of respiration. But besides this, certain instinctive acts, and even the simpler or habitual acts of locomotion, have been regarded as automatic, or as simple reflex movements, performed without the agency of the will. In the cold-blooded vertebrata, and still more obviously, in insects and myriapods, for example, simple progressive locomotion appears to be almost or entirely independent of volition; for decapitated centipedes will, if stimulated, run rapidly forward, will even raise their headless trunks over small obstacles, and force them persistently against more formidable ones; decapitated lizards exhibit similar, though less prolonged, movements. In the habitual movements of walking performed by ourselves, volition, and sometimes even consciousness, take but little or no part; and thus they become truly automatic. Many persons, moreover, as, *e.g.*, orators, actors, musicians and particular handicraftsmen, acquire by habit, or necessity, the power of performing very special movements, without the continued aid of volition; such movements have been named *secondarily automatic*, and have been supposed to be accomplished through the sensori-motor, or even through the purely excito-motor, nervous centres. They are, indeed, reflex actions of a higher order than the reflex movements *natural* to every one, and might be termed *acquired* reflex acts, or acts of *unconscious volition*, which itself, viewed as a cerebral process, is a reflex act of the highest order.

In passing from the functions of the cerebro-spinal nervous system, to a consideration of those of the sympathetic nervous system, we shall find, that this system also acts in a reflex manner, possibly solely and entirely in that manner, and that the reflex acts governed by it, are quite involuntary, and, at least in health, independent of sensation.

Functions of the Sympathetic Ganglia and Nerves.

The structure of the sympathetic nerves, and their anatomical connections with the cerebro-spinal system, afford reasonable ground for the opinion, that this remarkably complicated part of the nervous system is, neither physiologically, nor anatomically, to be considered as a mere portion of the cerebro-spinal nervous system, nor yet as a system independent of it; but that it is physiologically possessed of certain special functions, at the same time that it is, in many points, functionally associated with the cerebro-spinal system.

The nerve fibres, whether white or ganglionic, and the substance of the ganglia themselves, are, like the nerves and grey centres of the cerebro-spinal system, *conductors* of the effects of impressions made upon them.

Doubtless, also, the nerves consist of both *afferent* and *efferent* fibres, some of the afferent fibres probably terminating in the sympathetic ganglia; whilst some undoubtedly proceed through the ganglia on to the cerebro-spinal centres, and some also perhaps pass from the grey matter of the sympathetic ganglia, to the grey matter of the cerebro-spinal centres. The connections of the efferent fibres, are certainly with the ganglionic grey substance of the sympathetic ganglia themselves; and most probably also, they have indirect, or direct, connections with the cerebro-spinal nervous centres. There is reason to believe further, that the grey matter of the sympathetic ganglia, can not only conduct the effects of impressions, but may also *transfer* and *radiate* them. This grey matter of the various sympathetic ganglia, is also considered, by some, to be the seat, or centre of origin, of *special* nerve force, and the whole sympathetic system to be, so far, independent. Lastly, the power of the sympathetic nervous system, perhaps the force originating in its ganglia, may be inhibited, or interfered with, by the superior force of the cerebro-spinal nervous centres.

The sympathetic nervous system, considered generally, has for its function, the office of presiding over the viscera of the body, as its distribution implies. It has been named the *vegetative*, or *nutritive*, nervous system, and sometimes, from its distribution, the *visceral* nervous system. From the fact, that its branches reach their ultimate destination, supported upon the large and small arteries, and since they may be traced likewise on to the arteries of the trunk of the body and of

the limbs, it is probable that the greater part of the influence which they exert upon the viscera, and on other parts of the body, is exercised through a certain control over the muscular substance of the heart, and over the muscular coat of the arterial vessels. The sympathetic nervous system might be designated the nervous system of the vascular apparatus; its ultimate branches constitute the so-called *vasi-motor nerves*. We shall immediately see evidence of this control, and of the manner in which it appears to be exercised; and we shall find that, even in this function, it is more or less assisted by, and subordinated to, the cerebro-spinal system.

We may consider the special functions of this system, in relation to sensation, motion, nutrition, and secretion, and to the physiological connection between it and the cerebro-spinal system.

The sympathetic nerve, when the parts to which it is supplied, are in a state of health, does not appear to be *sensitive* itself, nor to transmit sensory impressions; for there is no feeling in the parts to which these nerves are distributed, when they are in a condition of health. In disease, however, cramps and other pains, sometimes of a most acute and depressing character, are experienced in them; the effects, as one would say, of an exaltation of the common sensibility without any tactile sense. In experimental irritation of the sympathetic, pain is produced, the amount of which seems to vary under different circumstances. In all cases, the stimulus must be powerful enough for the effects of the impression to be transmitted to the cerebro-spinal system, and reach the centre of common sensation; for the substance of the sympathetic is itself insensible, and the sensibility of parts supplied by its branches only, must be due to its connection with the cerebro-spinal system. Whether the effects of such impressions, are conducted by afferent fibres, running direct from the sympathetic nerves to the cerebro-spinal nerves, or whether they are first conducted to the sympathetic ganglia, and thence indirectly, by fibres originating in the grey matter of the sympathetic ganglia, is not quite certain. If the former be true, the reason why the parts supplied by the sympathetic nerves, are insensible in health, must be, because the number of afferent cerebro-spinal fibres in them is so few; if the latter view be correct, the insensibility of these parts in health, must depend on the interruption, or cutting off, of the sensory impressions at the ganglia. Again, the increased excitability, produced in

disease, either compensates for the paucity of the afferent fibres, or else causes the effects of the sensory impressions to be transmitted, with greater force, through the ganglia.

In regard to the control of the sympathetic nerve over the *motions* of the parts to which it is supplied, it is, in the first place, important to note, that this system is never the path of the voluntary motorial stimulus, the movements of all the parts being strictly involuntary, or entirely beyond the control of the will. Thus the movements of the intestines, in urging onwards their contents, are reflex, and excited, through the sympathetic nerves, by the mechanical stimulus of the food.

That the sympathetic nervous system influences the movements of the parts to which it is supplied, is proved by irritation of the nerve, and by its division. Irritation of the sympathetic nerve distributed to the iris, causes that membrane to contract in its width, so that the pupil becomes dilated.

The *lenticular* ganglion of the orbit, is the centre which governs the nutrition of the eyeball, and through which the movements of the iris, are accomplished; the sensory nerves of the eyeball, coming from the first division of the fifth, and the motor nerves from the third cranial nerve, pass through it, as elsewhere explained. The relative size of this ganglion, in animals, is proportionate to the activity of the iris, and to the general powers of sight; it is large in nocturnal animals.

Division of the sympathetic branch which connects the lenticular ganglion of the orbit with the superior cervical ganglion, causes immediate paralysis of the radiating fibres of the iris; and the pupil contracts, in consequence of the action of the circular fibres, which are governed through the oculomotor nerve of the eye. On the other hand, galvanic irritation of the lenticular ganglion, or of the cervical or dorsal portion of the spinal cord, with which the upper cervical ganglion of the sympathetic is connected (provided, in the latter cases, that the shocks are sufficiently powerful), is followed by contraction of the radial fibres, and consequent dilatation of the pupil. Irritation of the cervical portion of the cord, produces protrusion of the eyeball; whilst section of the same, causes its retraction, and also gives rise to partial closure of the eyelids, to a forward movement of the nictitating membrane, and to a narrowing of the nasal and buccal openings; irritation produces the opposite effects.

Irritation of the nerves of the heart, affects the movements of that organ. Galvanism, applied to the cervical part of the sympathetic, to the superior thoracic ganglion, to the branches connecting it with the spinal cord, or to the cervical portion of the latter, determines a remarkable acceleration of the heart's beats; in the two latter cases, in a less marked manner. The diminution in frequency of the action of the heart, by a weak stimulation, and its complete arrest, by a strong stimulation of the vagi nerves, have already been mentioned, as well as the weakening effect of removal of the cerebro-spinal axis. The pulsations themselves seem, therefore, to be determined by some influence emanating from the sympathetic nerve, but their force is governed by the cerebro-spinal axis.

In the same manner, irritation of the splanchnic nerves, of the thoracic portion of the sympathetic, or of the dorsal region of the spinal cord, causes movements in the intestines, ureters, and bladder; but very strong galvanic shocks diminish the intestinal peristaltic action.

These movements, even when excited by stimuli applied close to the ganglionic centre, and performed by parts near this centre, always occur slowly, and not instantaneously and spasmodically, as is the case with movements excited through the cerebro-spinal nervous system; they are more or less rhythmical, continuing to be performed, for some little time, at regular periods of succession, and passing off slowly. When these movements become languid, or even have altogether stopped, they may be increased in activity, or entirely revived, by the fresh irritation of the sympathetic ganglia or nerves. These peculiarities of the reflex actions of the sympathetic, have been attributed to the modifying and diffusive influence of the ganglionic cells, through which they are supposed to be transmitted. (Fick.)

The influence of the *vasi-motor* nerves over the smaller arteries, is shown by dividing the sympathetic nerves distributed to any part, as, for example, in the neck of a rabbit, when the small arteries of the corresponding side of the face, and of the ear, become dilated, the blood collects in them, and accumulates, as is manifested by their dark red appearance and increase of temperature, and by the general exaltation of the vital powers of all the tissues: the temperature is sometimes elevated as much as 18°; perspiration covers the skin; the venous blood is brighter, and coagulates more quickly than usual. The retina becomes more sensible

to light; the pupil contracts, the eyelids are partially closed, the membrana nictitans projects, the eyeball is retracted, and a flow of tears takes place. The muscles are more irritable; the rigor mortis appears more slowly, and lasts longer; inflammation and the reparation of injuries, effusion of serum, suppuration, and absorption of extravasated blood, and the process of cicatrisation, occur more quickly, and are more active. If now the upper portion of the cut sympathetic nerve be irritated by galvanism, the vessels again contract to their usual size, the parts assume their natural appearance and condition, and all the preceding phenomena are exactly reversed. These singular effects are more marked, if the cervical ganglia are destroyed. Other experiments likewise appear to exhibit the power of the sympathetic over the circulation, temperature, and vital properties of the tissues. Thus, division of the roots of the spinal nerves of the upper limb, before they leave the spinal canal, causes loss of sensation and motion in the limb, but no change of temperature; whereas division of the large nerves of the limb, subsequently performed, is at once followed by a rise of the temperature of the part, certain fibres being then divided, which must have their origin directly in the sympathetic ganglia, or else must pass through them, from some distant part of the spinal cord. (Bernard.) So also, increased vascularity and temperature of the lower limb, but no loss of sensation or motion, have been found to follow destruction of the lumbar sympathetic ganglia. But Schiff asserts, that the temperature of a limb is elevated, after section of the anterior roots only of its spinal nerves.

This control of the sympathetic over the calibre of the small arteries, is believed by some to explain its influence on the processes of *secretion* and *nutrition*. The former have been already mentioned, in speaking of the functions of the facial and fifth nerves; but it may be added, that the flow of tears from pain, and the partial sweatings of one side of the face, after division of the sympathetic of the same side, are further examples of this influence. The sympathetic vasi-motor nerves appear to act, by causing contraction, of the vessels, so as to diminish their calibre; and the dilatation which ensues on their division or exhaustion, not only increases the supply of blood, but also the permeability of the coats of the blood vessels themselves. Division of the sympathetic nerve in the neck, is, after a time, followed by opacity and ulceration of the cornea. The amaurosis, which is sometimes dependent on

the irritation produced by intestinal worms, is explained by supposing that the nutrition of the retina is impaired, owing to the contraction of the vessels, causing a diminution of its supply of blood. It was found by Brown Séquard, that when one hand was immersed in water at 32°, the temperature of the opposite hand fell, though that of the rest of the body remained unaltered; this effect he attributes also, to the diminution of the nutrient arteries, through the influence of the stimulus upon the vasi-motor fibres of the sympathetic system, transmitted to the opposite, but corresponding, part of the body. Whether this effect is due merely to the diminished supply of blood, or partly to the resulting interference with the ordinary nutritive changes of oxidation, is uncertain. Ice, applied to one wing of a bat, causes, in like manner, contraction, or even closure, of the vessels of the corresponding point of the opposite wing. If a freezing mixture be applied to the ulnar nerve at the elbow joint in the living body, the two inner fingers, at first, become slightly colder, but their temperature slowly rises, till they are at length some 9° or 10° warmer than the three outer fingers, owing to paralysis of their vasi-motor nerves; the temperature of the three outer fingers is probably lowered, on account of the diminished quantity of blood in the radial artery, so that this, in part, accounts for the difference in temperature. Pressure of the finger behind the ramus of the jaw, produces phenomena, some of which are similar to those observed on irritating the sympathetic in the neck; others, however, are due to irritation of the pneumogastric nerves; *e.g.*, heat and tingling of the ear, difficulty of breathing, cardiac and gastric disturbance, and even dilatation, and subsequent contraction, of the pupil.

The real nature of the dilatation of the vessels, which ensues on division or paralysis of the sympathetic nerves, is uncertain; some maintain that it is active, and that, just as the pneumogastric nerves serve to inhibit, regulate, or restrain the movements of the heart, so, in this case, some active dilating influence is the cause of the relaxation of the muscular coats of the vessels; according to others, however, the dilatation is passive.

It is remarkable, that movements similar to those already mentioned in the heart, the intestines, and in the coats of the small vessels, may be produced by irritation or division of certain portions of the spinal cord, those, in fact, with which the sympathetic nerves, supplying any given part, are connected; so that the influence of the sympathetic nerves, on the movements of

the heart, intestines, and coats of the arteries, would seem to be derived, in part at least, from the spinal cord and medulla oblongata, which are therefore *visceri-motor*, and *vasi-motor* centres. This appears to be especially true of the heart and stomach. It is even supposed, that the constant influence exerted by the sympathetic upon the smaller arteries, is owing to a stimulus conducted to those nerves, but originating in the cerebro-spinal axis. The same is said to be true, in regard to its power over the visceral movements. Thus the lenticular ganglion of the orbit, has been experimentally shown to be connected with the spinal cord between the sixth cervical and second dorsal vertebra, and also with the back of the medulla oblongata. The sympathetic nerves of the heart, are connected with the cervical and upper dorsal region, and those of the intestines, with the lower dorsal portion of the cord. It is further supposed, that when, from any cause, the ordinary amount of stimulus, proceeding from the spinal cord to the sympathetic, is withdrawn, the vessels then dilate, as in the act of blushing, and under other conditions, contract, so as to cause pallor. But these phenomena are also dependent on the relative force of the heart's action, as in passion or fear. The movements of the viscera may also be affected, as shown by agitation of the heart, or by increased peristaltic action of the intestines.

Emotional movements may likewise be produced in parts supplied by the sympathetic nerves, and the stimuli which produce them, must of course originate in the cerebrum or centre of the emotions. There is reason to believe, that *ideas* even may act in a similar manner.

Instinctive causes, or like actions of the cerebro-spinal system, may produce effects upon associated parts, which must take place through the sympathetic nerves; as, for example, when the act of sucking produces an accompanying increase in the flow of saliva. The similar increased secretion of the lachrymal gland in shedding tears, affords evidence of an emotional stimulus affecting a gland through its sympathetic nerves; and the flow of saliva, at the thought of a coming meal, affords similar evidence as regards ideational stimuli. Indeed, such glands as the lachrymal and salivary glands, which act only at certain intervals, and are particularly affected by mental states, receive, besides sympathetic nerves, many branches from the cerebro-spinal system. But strong mental stimuli may also arrest the lachrymal secretion, as is well seen when a person is overpowered by grief; in like manner, the flow of saliva may

be checked by strong emotions. It is probable that the gastric secretion is, like the saliva, also excited by mental stimuli; it has been seen to be rapidly secreted in fasting dogs, at the sight of food.

Of simple reflex acts, performed through the cords and ganglia of the sympathetic, we have numerous instances ; and in these cases, too, we shall find that sometimes they are performed through the intervention of the spinal cord ; though cases may be quoted, in which the sympathetic must act altogether independently of the cerebro-spinal system. Thus, it is said, when the visceral nerves of the abdomen of an animal are powerfully galvanized, movements of the abdominal muscles are excited ; and irritation of the frog's intestines or liver, will also excite movements in certain voluntary muscles.

In the human subject, too, both the striated and non-striated muscles may be affected through the sympathetic nerves, for strabismus or squinting, convulsions in infants, and epileptic attacks in the adult, are sometimes caused by worms, or irritating substances, in the alimentary canal; moreover, a form of paralysis, known as reflex paralysis, and certain muscular symptoms, showing disturbance of the nervous system, are sometimes induced by disease or irritation of distant viscera, or of highly sensitive parts, such as the dental nerves ; whilst colic and even diarrhœa frequently result from the introduction of irritant substances into the alimentary canal, and from the irritation of teething in infants. In the foregoing cases, it would seem that the fibres of the sympathetic system, play an afferent part as regards the stimuli employed; and that the effects of the stimuli, are conveyed to the reflex centre of the spinal cord, and thence act upon efferent fibres belonging to the cerebro-spinal system. But, in the second place, examples of reflex acts, performed through the sympathetic, quite independently of the cerebro-spinal system, are found in the case of those movements of the intestines, or of the heart, which continue after the trunks of their nerves are divided, or even after they have been entirely removed from the body. The apparatus through which the movement, in such cases, is excited must be the sympathetic nervous system. When, indeed, a stimulus is applied, under such circumstances, to a part of the intestine, or to a portion of the heart, the movement produced is not merely local, but is transmitted, or propagated, to neighbouring parts ; and, instead of producing only a single motion, as would be the case in a detached voluntary muscle,

the movement is continued, and even follows the ordinary peristaltic or rhythmic character. The centres, through which the effects of the stimulus are thus extended beyond the immediate seat of their application, are the intrinsic or visceral ganglia, to and from which, afferent and efferent fibres convey the effects of the stimulus, in the ordinary reflex manner. According to another view, these ganglia, during life, are the centres of a direct governing force, which regulates the movements of the parts, that is to say, a central stimulus originates in them, independently of the effects of stimuli conveyed to them by afferent fibres. The details of this subject, will be found in the Sections on Digestion, and Circulation, in the account of the movements of the heart and the intestines, and of their dependence on the nervous system.

As already stated, the movements of the heart and intestines, whether performed by reflex actions, governed through the sympathetic system, or by the action of direct centric stimuli, originating in the sympathetic system, and entirely beyond the control of the will, may be affected through the cerebro-spinal system, by exciting or depressing ideas and emotions. Lastly, experiments show that the sympathetic is so far dependent on the cerebro-spinal axis, that stimulation of certain parts of the brain, excites movements in the muscles of vegetative life; and that, after destruction of brain and cord, the general sensori-motor functions of the sympathetic are lost.

Influence of the Nervous System on Nutrition and Secretion.

There is abundant evidence, which will be hereafter detailed in the Sections on the above-named subjects, to show that the processes of nutrition and secretion can be influenced through the nervous system. There is reason to believe that the part of the nervous system here specially concerned, is the sympathetic nervous system, experiments having shown that when the sympathetic nerves, supplying a part of the body, are divided, the nutrition of that part is immediately interfered with; and when the sympathetic nerves belonging to a gland, are divided, its secretion is arrested. The reflex action of the sympathetic system on secreting glands, is well exemplified by an experiment in which, when the œsophagus was divided, a large quantity of saliva was secreted, on injecting broth into the stomach. (Gairdner.)

The effects of division of the sympathetic, in causing dilatation of the vessels, and congestion of any part, by paralysing the muscular fibres of the coats of the small arteries, which have already been noticed (p. 389), are supposed to offer an explanation of the mode in which the sympathetic nerves may influence the processes of nutrition and secretion, as observed in the increased flow of tears and saliva, under certain circumstances; but, besides that *indirect* mode of action, it appears probable, that the nerves may, in certain instances, exercise a *direct* influence over the various chemical processes of nutrition and secretion (see *Secretion and Nutrition*). The function of nutrition would seem to be more intimately connected with the sympathetic, than with the cerebro-spinal system; for it has been found that, in frogs, the nutrition of the parts to which the spinal nerves are distributed, is much more impaired, when these are divided after they have passed the inter-vertebral ganglia, than when they are divided behind those ganglia. (Axmann.) In like manner, division of the fifth cranial nerve in front of the Gasserian ganglion, leads to more rapid inflammation, and consequent destruction, of the eye, than division of the same before it enters the ganglion. (Magendie and Longet.) Lastly, it has been noticed, that paralysis of both the sensory and motor roots of the spinal nerves, is followed by greater disturbance of nutrition, than when the motor roots only are implicated.

Bilateral or Double Action of the Nervous System.

In describing the nervous system, we have repeatedly alluded to the strictly bilateral character of its anatomical construction; and in treating of its functions, it must not be forgotten, that it possesses a perfect physiological duality; and this fact, coupled with the decussating structures met with at certain points, and with the cross action of those parts from side to side, leads to certain curious results.

Thus, passing from below upwards in the cord, sensory impressions cross over to the grey matter of the opposite side, immediately through the whole length of the cord; whereas, the motor impressions pass from side to side in the medulla oblongata. In the cerebellum, the cross effect is noticed in the rolling over, or turning round of the animal, on the opposite side to that on which an injury is inflicted; though this might depend, either on stimulation, or on loss of control, of the

muscles of the opposite side, or on a loss of power of the muscles of the same side; still, there is a cross effect. In regard to the large ganglia at the base of the brain, similar cross effects are noticeable, injuries to the optic thalami, or corpora quadrigemina, affecting vision in the opposite eye. The decussations at the optic commissure, also lead to remarkable results in reference to vision, which will be noticed in the Section on Sight. Above the medulla, in the pons, and in the peduncles of the cerebrum, the cross effect is also manifested, both as regards sensation and motion; for the paths of both have already decussated lower down. Lastly, it is maintained, that many of the radiating fibres of the cerebral hemispheres, pass over from one hemisphere to the other, through the corpus callosum; and, in any case, the two hemispheres, as well as all the other parts of the bilateral nervous centres, are closely connected together by commissural structures, both grey and white.

In reference to sensation and motion, the action of a bilateral nervous centre, is explained by the bilateral structure of the parts with which it is connected through its nerves; but the unity of the mind, that is of the conscious part of our nature, and its various reactions on the body, seeing that the brain is double, have constituted a perplexing problem to certain physiologists. Ordinarily, both hemispheres probably act together, each part of the two being respectively associated by its commissural connections. But it has been shown, that one is sufficient for the persistence of all the mental faculties, and of their determining influence on the body; for considerable portions of one hemisphere have been cut away by the sword, or otherwise, and very much larger portions have been altered or destroyed by disease, and yet all the mental faculties have been preserved. These and other considerations have led to the adoption of the opinion, that the mind itself has a dual action, and that it is possible, that when two concurrent trains of ideas or thought, pass together through the mind, the cerebral hemispheres are acting differently, or in a dual manner, though ordinarily they act together. (Wigan).

Sleep.

Sleep consists in a temporary suspension of the functions of the cerebral portion of the nervous system. It may be defined to be a periodical rest of the organ of consciousness, as

regards the outer world; so that this is no longer sensible to its ordinary stimuli. Sleep and the waking state have been described as the result of a kind of antagonism between the organic and the animal life; the functions of animal life, governed by the mind, enjoy, from time to time, freedom of action, whilst at other times, they are repressed by the organic force acting in obedience to a law of creative nature. (Müller.) The cerebral hemispheres, and the sensory ganglia at their base, like all other parts of the body, undergo, in the exercise of their functions, a waste of tissue; hence they require rest, that new matter may be added to them, to compensate for the waste and disintegration of their substance. During sleep, however, all the functions of vegetative life continue to be performed. The pulsations of the heart, the circulation, the movements of respiration, the interchange of gases through the lungs and skin, and the chemical and mechanical phenomena which accompany digestion, absorption, secretion, and nutrition, pursue their course. The movements of the muscles concerned in these functions are, however, somewhat less frequent than during the waking state; thus the respirations become slower or fewer in number, though deeper; the beats of the pulse diminish in number. On the other hand, the action of certain voluntary muscles, as, for example, of those which roll the eye-balls upwards, is increased. The iris is contracted. The various excretions are less abundant; but the quantity of phosphoric acid separated by the kidneys, is said to be somewhat increased. The animal heat is also lowered, hence the sensation of cold which is often felt on awaking. The quantity of blood in the vessels of the brain, and the rapidity of its circulation, are both much diminished. (Durham.) This observation is contrary to the old opinion, that sleep was the result of a turgescence of the vessels of the brain; but it is confirmed by the state of the retina or expansion of the optic nerve, which has been found, by aid of the ophthalmoscope, hereafter described, to be paler and less vascular during sleep. (Hughlings Jackson.) It has been suggested, that the blood vessels of the choroid plexuses in the ventricles of the brain, may become more turgid during sleep, and, by a sort of erection, may act as diverticula for the blood in the cranium, whilst the cerebral vessels are proportionally emptied. The less full state of the vessels of the brain substance, has been called its nutritive circulation, and the more full condition, its functional circulation; the vessels of both the choroid

plexuses and the brain, may be understood to be governed by the state of the vasi-motor nerves.

Reflex movements still occur during sleep, for the excitability of the afferent and motor nerves, and of those parts of the nervous centres which are not necessary for conscious sensation, but which govern the reflex movements, still remains. The periods of remission and rest of vegetative life, therefore, do not coincide with those of animal life; moreover, they present very great variations in different organs. Thus the heart's substance and its nervous ganglia, must take their rest in the intervals between its pulsations; the respiratory muscles and nervous centres, between the inspirations; and the secreting glands, during the abeyance of their function.

The *causes* of sleep are mental and bodily fatigue, long continued exertion of the senses, diminution or absence of external impressions, as silence and darkness, monotonous continuance of sensory impressions, as, for example, the humming of bees, also heavy meals, spirituous drinks, certain narcotic agents and cold. The recumbent posture also induces sleep, not only through habit, but also by increasing the tendency of the blood to the cranium, thus probably causing temporary fulness of the vessels of the choroid plexus, and so diminishing the quantity of blood in the grey matter of the cerebrum.

As regards the internal physiological conditions of sleep, but little is known.

The act of *awaking*, or the cessation of the temporary suspension of the cerebral functions, is either spontaneous, when the nervous parts have recovered from their fatigue, or else it is caused by internal or external stimuli; and this latter is one of the principal points of distinction between sleep and coma, or that absolute state of insensibility from which a person cannot be aroused. Amongst the internal stimuli which interrupt sleep, may be mentioned, very vivid dreams, pain, or sudden disturbances in muscles connected with organic life, as, for example, those of respiration, or the uneasy sensations produced by distension of the intestines or bladder. The external stimuli which interrupt sleep, are strong sensory impressions, such as sound, light, or mechanical disturbance, as, *e.g.*, shock or shaking; the cessation of habitual impressions, on the other hand, may also put an end to sleep—the miller awakening when his mill stops.

Violent sensory impressions, mental excitement, and certain substances, such as tea and coffee, retard sleep, but after severe

and prolonged watching, it eventually comes on with greater intensity; cases, indeed, are related of fatigued soldiers sleeping on the march, or even during a cannonade in battle, and of persons slumbering during the infliction of torture. Cases have occurred in which, after sleep has been postponed for several days, it supervened so profoundly, as to pass into coma and death; the celebrated French anatomist and surgeon, Portal, died in this way.

Sleep is necessary for the maintenance of the functions of animal life, and is common to all animals which possess a nervous system. The suspension of the nutritive functions in the lowest animals, which are destitute of nervous substance, if any such exist, and that noticed, during the night, in the leaves and other parts of plants, is not true sleep.

Various circumstances modify the *amount* of sleep required by different persons. Thus, *age* is of great importance; for adults spend, on an average, about one-third of their life in sleep, *i.e.*, about eight hours in the twenty-four; infants pass almost the whole, and children more than half their existence in a state of sleep; whereas by old people, less is required; but in extreme old age, life, as in infants, may be said to be almost a continuous sleep. *Temperament* also influences the amount of sleep; thus persons of a plethoric or lymphatic temperament, require more sleep than individuals of a nervous temperament. *Habit*, again, modifies considerably the amount of sleep required by the individual. Pichegru, it is said, only slept four hours out of the twenty-four, during one year's campaign. John Hunter and Frederick the Great required only five hours daily. Lastly, the amount of previous fatigue, whether mental or bodily, of course influences the amount of sleep required. The *invasion* of sleep is, in some individuals, sudden; but it is generally gradual. It is marked by heaviness of the eyes, yawning, and an endeavour to obtain an easy position; luminous spots, bright bodies, and indefinite images, are sometimes perceived, showing the gradual decline of the powers of attention. The imagination is, to a certain extent, active when the senses and the reasoning faculties sleep. The functions of sight are first suspended, then those of taste, smell, hearing, and, last of all, that of touch. The muscles of the limbs are the first to become relaxed; whilst those of the back are the last over which voluntary control is lost. Sleep is sometimes protracted for twenty-four hours, or more, in succession. The act of *awaking* is sometimes sudden,

but an intermediate state generally exists between sleep and waking. Sleep may be heavy or light, the one state gradually passing into the other; this varies in different individuals. It is most profound and most refreshing during the first hours of rest, many persons being then even insensible to the most powerful external impressions. When sleep is of a light character, very slight stimuli suffice to rouse the individual; in such a condition, many ordinary occurrences are perceived, and not unfrequently, the resulting ideas interweave themselves in the formation of dreams.

During sleep, indeed, although the mind is insensible to external impressions, yet the mental faculties may be in a state of internal activity, simple ideas being formed, or even general notions conceived. This state constitutes *dreaming*. The current of thought, in this condition, is totally independent of the will. Ideas commonly follow each other, in a more or less incongruous manner, sometimes, however, in a uniform and regular order. The character of dreams is influenced by the mental condition in the waking state; hence, when the mind has been busily occupied during the day with certain ideas, these frequently form the subject of dreams at night; so also, when labouring under depressing emotions, dreams during sleep are of a mournful and agitating character. The reasoning faculties are sometimes correctly exercised; cases are on record, of mathematicians solving the most difficult problems in their dreams.

One of the most remarkable and characteristic phenomena of dreaming, is the rapidity with which ideas pass through the mind, events of a life-time sometimes appearing to occupy but a few seconds. There is frequently total inability to perform certain movements, however great the wish to do so may be; the inability to strike a desired blow, or to escape from, or avoid, an imaginary danger in a dream, notwithstanding all our efforts, affords a familiar example of this fact. This, as well as the simple sensation of weight upon the chest, is a form of *incubus* or *nightmare*. It is unknown whether dreaming may be prolonged during the whole period of sleep, or whether it is confined to short intervals between sleeping and waking. The former view is somewhat supported by the occurrence of repeated movements and ejaculations, occasionally observed even in heavy sleepers, and of which they lose all recollection on awaking. But the prevailing opinion is, that dreams are only possible in light or imperfect sleep,

and that they are incompatible with the condition of the mind in profound sleep. Those dreams which occur during the short interval between sleep and waking, are certainly the best remembered. In light sleep, at the beginning of sleep, when the activity of individual parts of the cerebrum, has not yielded to the general state of repose, or, at the end of sleep, when those parts have already regained some degree of consciousness, certain mental faculties come into operation, and, by a process of combination, form an ideal and imaginary world. The whole picture is so unreal, and the dreamer is so conscious of it, that often, even during sleep, he knows that he is dreaming; so conscious, indeed, is he of this, that he can either prolong the dream, or at once put an end to it. This condition is, therefore, hardly one of real dreaming, but approaches more nearly to the waking state. Such dreams remain impressed on the memory, with more or less distinctness.

Though, in certain dreams, external impressions may be correctly perceived and combined, it often happens that they are misapprehended, wrongly interpreted, or even ludicrously associated. Thus the effects of cold air, or of evaporation on the skin, may be construed into the touch of an imaginary person or ghost. Many other delusions may be thus explained.

Lastly, internal conditions of discomfort may produce perfect or imperfect impressions, and so give rise to dreams; and may, like external impressions, be rightly or wrongly interpreted in the dreaming state.

That kind of dreaming, in which the individual performs actions, and even speaks, as if awake, without the co-operation of the will, is known as *somnambulism.* In this state, the movements and conversation are determined by the ideas of the dream; but attention to other ideas or impressions, and memory, are entirely suspended; whilst the reasoning is limited, and the control of the pure will over the mental processes, is also abrogated. The mind is absorbed in one current of ideas alone. The regular marching of soldiers in sleep, when much fatigued, and the answering of questions, by persons in a state of slumber, are examples of the lighter forms of somnambulism. In the more marked forms, chiefly occurring in hypochondriacal or hysterical individuals, the dreamer performs the most dangerous acts, follows the most perilous paths, and the most unfrequented ways, which he would be

unable to do if awake, totally unconscious of any danger. He can see and hear, can dress and undress, opens doors and boxes, and, on awaking, has no recollection of what has happened. In this peculiar state, the body may be altogether insensible to pain, the ear to sound, and the eye to light, however powerful the action of these stimuli. Impressions are not perceived by the senses, so long as the attention of the individual is directed to some other subject or object; but the sensibility of any one sense is much heightened, when the mind is occupied exclusively with ideas solely connected with that sense. Sounds, which in the waking state would hardly be noticed, now appear to produce powerful impressions. In the same manner, the sensibility of the skin, when the attention is directed to it, is greatly exalted; and so on with the other senses. Cases are even recorded, of individuals performing every action suggested; such as fighting, swimming, or hunting; some will imitate drunken men; others will work out the most difficult problems, or go through a train of reasoning; speeches have been made, verses composed and committed to writing; in fact, the attention of a somnambulist can often be directed, at the will of an observer, to any given object or subject. Although, on awaking, he has no remembrance of what has taken place, yet, on relapsing into a similar state, the ideas previously expressed, and the acts performed, may be resumed and continued. Persons who exhibit this extreme degree of somnambulism, have been said to have a *double consciousness*, one memory when awake, another when dreaming. (Wigan.) In some individuals, this state may be artificially induced; but it is generally a natural phenomenon.

The so-called *magnetic* sleep or *hypnotism*, which sometimes occurs spontaneously in nervous persons, but which is more frequently induced by the operations of so-named *animal magnetism* or *mesmerism*, is a similar mysterious phenomenon; and the constitution which predisposes to it, seems to depend on analogous abnormal states. It is chiefly observed in nervous, highly excitable, hysterical females. Its occurrence has been placed beyond a doubt, by the evidence of many observers. Indeed, new mental faculties have appeared to some, to have been developed, or to have been aroused from a dormant state, by means of mesmerism. Many remarkable movements and actions may, in such persons, undoubtedly be excited by suggestion; powerful contractions of the limbs may be induced, and even certain movements, impressed by others upon

the magnetised individual, may suggest corresponding ideas in his mind, lead to the performance of further movements, and so appear to place the individual under the control of the operator.

The manifestations of the so-called *clairvoyants* and *spirit-rappers*, probably rest upon erroneous explanations of facts. Under impressions repeatedly acting on the mind, unusual so-called subjective phenomena may be induced in highly excitable persons, through the medium of the nervous centres. In the delirium of fever or of insanity, the thoughts, expressions, and acts of the patient, are often directed by an occasional question or remark made by a bystander; hence credulous persons may perceive, in the expressions of such individuals, supernatural manifestations; and similar phenomena are induced by so-called animal magnetism. It usually happens that, in questions of this intricate nature, those are the most dogmatic who, by their previous habits of thought and education, are the least qualified for such investigations. No right of opinion upon such difficult questions can be granted to enthusiastic dilletanti, or to the worshippers of a longing desire for notoriety.

THE NERVOUS SYSTEM AND ITS FUNCTIONS IN ANIMALS.

The nervous system in animals has already been described (pp. 124 to 131). In the Vertebrata, it is constructed on a plan similar to that of Man, consisting of a *cerebro-spinal* system, composed of brain, and spinal cord, with cranial and spinal nerves; and of a *sympathetic* system, composed of a double ganglionated cord, with branches of distribution. In the Mollusca, the nervous system is composed of ganglia scattered through the body, and of nervous cords connecting them, or passing from them, to be distributed to the various parts of the body. In the Molluscoida, there is but a single central ganglion, with branches of distribution. In the Annulosa, there exists a series of ganglia with intervening cords, arranged like a chain, on the under surface of the body, and having numerous branches proceeding to the various segments and their appendages. In the Annuloida, as in the Molluscoida, either the ganglionic centre is single, or numerous connected ganglia correspond with the radiated form of the body. In the Cœlenterata, the nervous system, when seen, consists also of a central ganglionic mass, with nerve trunks proceeding from it. In the Protozoa, no nervous system has been discovered.

However varied in its anatomical disposition, in different animals, the nervous system consists essentially, of a central mass or masses of grey matter, connected, in various ways, with nerve fibres; many of these, as in the cerebro-spinal axis of the Vertebrata, and in the multi-ganglionated system of the Mollusca and Annulosa, are connecting or commissural between different grey masses; whilst others form the branches, called nerves, proceeding from the grey matter. Physiologically con-

sidered, there can be no doubt, as indeed experiment sufficiently demonstrates in certain cases, that, in animals as in man, even in the simplest forms, in which the nervous system consists of but a single ganglionic centre, the nerve fibres act internuncially, as mere conductors of the effects of impressions produced upon them; whilst the grey matter, whether aggregated in certain parts of a cerebro-spinal axis, or collected in a small ganglionic mass, is not only a conductor of the effects of impressions, but may transfer, radiate, or reflect those impressions, and may constitute a central sensorium, for the reception of sensory impressions, and, in the higher animals, a centre of origin of motorial stimulus. The grey matter always manifests higher endowments than the nerve fibres, whether white or ganglionic. As we have seen, in the study of the human nervous system, some of these fibres must be afferent and some efferent; certain afferent fibres are concerned in the conduction of sensory impressions only, as, for example, the nerves of sight; whilst others conduct the effects of stimuli to the grey matter, from which a motor influence is reflected upon certain efferent fibres, in reflex actions, either sensori-motor, or simply excito-motor; whilst lastly, other efferent fibres conduct motorial impressions, which have, according to the position of a given animal in the scale, a more or less distinct ideational, emotional, or volitional character. As in man, too, the effects of the volitional stimulus, are of course directed upon the muscles concerned in locomotion; whilst the involuntary, or reflex, movements partly occur in the locomotive muscular system, and partly, as in man, in the muscular structures concerned in the functions of vegetative life.

The amount of nervous force manifested by any animal, whether in the phenomena of sensation, or of the regulation of its voluntary and involuntary movements, is strictly in accordance with the relative mass, and complexity of organisation, of its nervous centre or centres. It is certain, therefore, that sensation and the power of regulated motion, as well as the higher psychical endowments, by which the animal is governed through trains of ideas, emotions, memory, reasoning processes, and will, are more highly developed in the Vertebrata, than in the lower subkingdoms, in which, at length, all sensation and regulation of movement must be reduced to a minimum, and so finally become extinct. As we descend in the scale, the higher psychical endowments first fade away; the ideational, emotional, reasoning, and volitional faculties disappear, probably not being manifested by any creatures below the Vertebrate type; and, even in the highest of these, the controlling power of the will over the direction of the thoughts, so peculiarly marked in man, is of doubtful existence. Sensori-motor power, or pure instinct, still persists as the special *automatic* paramount guiding force, as in insects, for example. In yet lower forms, the movements are probably not even instinctive, but excito-motor or purely reflex; and lastly, in the very lowest forms, the movements are probably performed by the immediate stimulation of an insensible contractile tissue, altogether independent of nervous influence, as in the case of the ciliary motion of the Infusoria, or of the irregular movements of the Amœba. Even in the highest animals, the ciliary motion, as already stated, appears to be independent of the action of the nervous system.

Whilst, however, in the preceding general sketch, it is assumed that the nervous system dies out, or disappears, before we reach the lowest

confines of animal existence, because no nervous system has been there detected, yet it has been maintained by some, that nervous substance may possibly exist in microscopic ganglia which escape detection; or that it may be diffused, in the shape of single nerve cells, in the bodies of the minuter organisms; or lastly, that it may even form a portion of the contents of a uni-cellular animal, that is, of an animal organism consisting but of a single nucleated cell. If these conjectures be true, we must conclude, that no animal exhibits movements, resulting from the direct stimulation of its contractile substance by external agents; but that, even in the very simplest forms, nerve substance may regulate those movements.

The nervous system is an apparatus, working so completely in accordance with its structural peculiarities, that the successive stages, by which its functions are gradually simplified, may be best followed, and its adaptations to the actions and wants of animals of lower and lower organisation, be most readily understood, by tracing the numerous gradations, both general and particular, which it presents in different animals.

Vertebrata.

The *Encephalon*, or entire brain. The only animals, in which the entire encephalon is absolutely heavier than in man, are the very largest cetaceans and pachyderms; thus, in the whalebone whale, its weight is about 5 lbs., and, in the elephant, it varies from 8 to 10 lbs., being heavier than in any other known animal.

The weight of the encephalon, as compared with that of the body, diminishes in the Vertebrata generally, in the following order and manner. In Mammalia, it is as 1 to 186; in Birds, as 1 to 212; in Reptiles, as 1 to 1321; and in Fishes, as 1 to 5668. (Leuret.) Amongst the Mammalia, the encephalon, as compared with the body, is proportionally smaller in the larger species, than in those of less dimensions; thus, in the ox, it is as 1 to 860; in the elephant, as 1 to 500; in the horse, as 1 to 400; in the sheep, as 1 to 350; in the dog, as 1 to 305; in the cat, as 1 to 156; and in the rabbit, as 1 to 140; in the rat, as 1 to 76; and in the field mouse, as 1 to 31. In all these cases, with the exception of the last, the brain is heavier, relatively to the body, than it is in man, in whom the average proportion is as 1 to 36·5. In a few other animals, the entire brain is also heavier, relatively to the body, than it is in man; as in the marmozet monkey, in which the proportion is as 1 to 22, and in certain small singing birds, as the linnet, goldfinch, and canary, in which the proportions vary from 1 to 24, to 1 to 14, whilst in the blue-headed tit, the ratio is even as high as 1 to 12. From these facts, it appears that, in comparison with the size of the body, Man has a far larger brain than the Vertebrata, even than the warm-blooded groups; but there are exceptions, in the case of a few small birds, in certain small rodent animals, and in the smallest of the monkey tribe. According to recent observations, however, the entire brain of man is heavier, in comparison with the body, than it is in the anthropoid apes, the proportion, in an adult Chimpanzee, being about 1 to 50. These facts, especially those derived from a wide comparison of the weight of the brain and body, in the different classes of the Vertebrata, show such a correspondence between the relative size of the brain and the amount of intelligence exhibited by those animals, as to justify the general inference, that the brain is that part of the organism, through

which, the manifestations of intelligence take place; for, with apparent exceptions, too few to influence the general conclusion, these facts demonstrate the large relative preponderance of the brain in man, associated with his higher mental endowments. In reference to the numerical estimates, above given, of the ratio between the size of the brain and the weight of the body, it must, however, be remarked, that the sensory and motor ganglionic masses, at the base of the cerebrum, viz. the optic thalami and corpora striata, are always included in the weights; and moreover, that these parts, in the lower Mammalia, and especially the corpora striata, in Birds, constitute, by far, the larger part of the so-called cerebral lobes. Hence the numbers do not show the relative size of the parts supposed to be concerned in the manifestation of intelligence, viz. the cerebral hemispheres, properly so-called. Correct estimates would necessitate the removal and weighing of the parts which really form the hemispheres in the lower Vertebrata. But, besides size, other conditions have to be considered, particularly the extent of surface and complexity of structure, the quantity of grey matter, and the number of commissural fibres.

The same general physiological deduction is justified by a comparison made by Sœmmerring, between the transverse diameter of the brain and that of the medulla oblongata, regarded as representing the great *root* of the various nerves of the body. Thus, in man, the width of the cerebrum as compared with the medulla oblongata, is as 7 to 1; in the orang-outang, 6 to 1; in monkeys generally, 5 and 4 to 1; in the cat, 2·75 to 1; in the rabbit, 2·66 to 1; in the horse, 2·625 to 1; and in the ox, 2·6 to 1. Again, the weight of the entire brain, as compared with that of the spinal cord, which in man is about 40 to 1, is, in the mouse, 4 to 1; in the pigeon, 3·5 to 1; in the newt, ·55 to 1; and in the lamprey, ·013 to 1; showing a progressive diminution in the brain, as compared with the cord, in the mammal, bird, amphibian, and fish. In the last two cases, it will be noticed, that the brain weighs even less than the cord; and it is in such animals, that we find the movements become more and more sensori-motor or instinctive, or even purely excito-motor or reflex, movements which, as we have already seen, are governed by the spinal cord, the medulla oblongata, and their extensions upwards, to the base of the cerebrum, rather than by the cerebrum properly so called.

Not only does the *size* of the entire encephalon, become relatively less, as we pass from the highest to the lowest Vertebrata, but this part of the nervous system undergoes a gradual simplification in its *form* and *structure*, more especially as regards the parts which, in this series of animals, represent the *cerebral hemispheres* and the *cerebellum*. These organs, indeed, so decline in size and complexity, that they become gradually smaller, in proportion to the sensori-motor ganglia at the base of the cerebrum; or, in other words, as we descend in the vertebrate scale, these ganglia exhibit a greater proportionate size, as compared with the diminished cerebral hemispheres and cerebellum. With the diminution of the cerebellum, there appear to be associated a diminished complexity and variety of the muscular movements executed by the lower Vertebrata; whilst the remarkable defect in the cerebral hemispheres, is accompanied by defective intelligence.

The *Cerebral Hemispheres.* — In the most intelligent mammiferous animals, the anthropoid apes, these parts completely cover the olfactory

nerves or lobes in front, and the corpora quadrigemina behind, being, indeed, as in man, prolonged so far backwards, that they completely cover, and even overlap the cerebellum. In many species of the still lower baboons and monkeys (fig. 63, *g*), the amount of overlapping is even greater than in man. But in descending through Carnivora, *e*, Cheiroptera, Ruminantia, and Pachydermata, and the still lower Rodentia, the cerebral hemispheres no longer overlap, but soon cease even to cover any part of the cerebellum, which ultimately is completely visible, when the encephalon is viewed from above. In the Ruminantia, *f*, the anterior part of the hemispheres, is also so proportionally diminished, as to permit the large olfactory lobes to project beyond

Fig. 63.

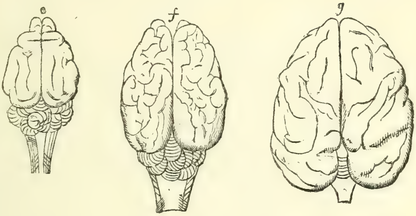


Fig. 63. Brains of three of the Mammalia, to show the gradually increasing size and complexity of the cerebral hemispheres, in the ascending scale of those animals. *e*, brain of the cat, showing the cerebrum, and its few simple, almost exactly symmetrical convolutions: behind it, is the much lobulated cerebellum and the medulla oblongata; and, in front, a portion of the olfactory lobes. *f*, brain of the sheep; the olfactory lobes are almost hidden, and the cerebellum is about half covered by the cerebral hemispheres, which are now more complex and less symmetrical. *g*, brain of a monkey, in which the olfactory lobes in front, and the cerebellum behind, are completely overlapped by the cerebrum; the convolutions are now constructed on the plan observable even in the human cerebrum: a distinct posterior lobe can be recognised, but the cerebrum is more pointed in front, its convolutions are more simple and symmetrical, and its relative size is very much smaller than in man.

them; whilst in the Rodentia (fig. 64, *d*), owing to the still further diminution in the hemispheres, even a portion of the corpora quadrigemina behind, becomes visible. In Birds, *c*, the cerebral hemispheres overlap the small olfactory lobes in front; but behind, a very large portion of the optic lobes is visible. In the Reptiles and Amphibia, *b*, a still further reduction of the cerebral hemispheres takes place. Lastly, in the Fishes, *a*, they are relatively so small, as merely to invest the corpora striata with a thin layer of cerebral substance; in these lowest Vertebrata, the parts of the encephalon are, so to speak, analysed, being arranged in a series of three pairs of ganglionic masses, placed in a double symmetrical row, one behind the other, and of a single median mass behind them. The

anterior pair of these ganglionic masses, form the *olfactory lobes*; the second pair, named the *cerebral lobes*, are composed of the corpora striata, covered with a thin layer of cerebral substance, which forms the rudimentary cerebral hemispheres; the third pair, usually the largest,

Fig. 64.

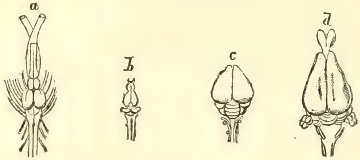


Fig. 64. Views of the upper surface of the brains of a fish, amphibian, bird, and mammal, showing the gradual increase in the size of the cerebral hemispheres. *a*, brain of the cod fish, showing, from behind forwards, part of the spinal cord, the back of the medulla oblongata, the median cerebellum, the two large optic lobes, the small cerebral hemispheres, consisting chiefly of the corpora striata, the narrow olfactory lobes and olfactory nerves, and lastly, the decussating optic nerves. *b*, brain of the frog, in which the cerebral hemispheres are the largest masses; the olfactory lobes are seen in front, and the optic lobes, projecting laterally, behind; the cerebellum is a thin transverse lamina. *c*, brain of the pigeon; the largest masses are the cerebral hemispheres. In front, are seen the ends of the olfactory lobes; behind, the cerebrum, and projecting at the sides, are the optic lobes and corpora quadrigemina; and, in the middle line, the laminated central lobe of the cerebellum, with its small lateral appendages. *d*, brain of the rabbit, showing, in front, the large olfactory lobes; next, behind them, the cerebral hemispheres, pointed in front, slightly sulcated, and now, by far the largest mass of the encephalon: behind them, the cerebellum, and its floccular appendages; and lastly, the back of the medulla oblongata.

correspond with the optic thălami and corpora quadrigemina, and, as they give origin to the optic nerves, they are called the *optic lobes*. Behind them, is the small median mass, representing the *cerebellum*.

In Fishes, therefore, the thin cerebral hemispheres must fulfil a very subordinate office in the nervous functions; in Amphibia, Reptiles, and even in Birds, they are still small, and their component grey matter is of but little thickness; but so largely developed as they are in the Mammalia generally, especially in the highest forms, and, above all, in Man, they appear, as already mentioned, more like superadded parts, overlapping all the other encephalic masses.

The progressive complexity of *surface*, of the cerebral hemispheres, is indicated by their smoothness in Fishes, Amphibia, and Reptiles; and by their faintly marked sulcation in certain Birds. In the lowest Mammalia, and even in the smallest and lowest genera of the highest order of Mammals, the hemispheres are also smooth, or nearly so, as, for example, in the Monotremata and Marsupialia, in the lowest Rodentia, and even in certain lemurs, the lowest of the so-called Quadrumana. As we advance in the ascending series of Mammalia, or in the ascend-

ing series of genera in certain Orders, the hemispheres become more and more sulcated on the surface, and finally, are modelled into the curved or tortuous ridges called convolutions, which, speaking generally, become more and more numerous and complex, as we reach the highest Mammalia, or the highest genera in the several Orders.

These *cerebral convolutions*, which may be said to be peculiar to the brains of Mammalia, may be considered—first, in reference to their general *plan* in any given group or groups; and secondly, as regards their relative *complexity* within that plan. In the Pachydermatous and Ruminant animals, for example, the convolutions are chiefly arranged in the form of parallel folds, extending from the front to the back of each hemisphere; and, for the most part, present a more or less flexuous outline. In the Carnivora, on the other hand, the surface of the hemispheres, is divided into four principal antero-posterior convolutions which seem to bend, in simple curves, around the upper end of the Sylvian fissure, one above the other, and pass continuously from the anterior or frontal, into the middle or parieto-temporal lobe. In neither of these Orders, nor in those lower in the scale, as the Rodents, Marsupials, and Monotremes, is there a distinct portion of the hemispheres, marked off from the other lobes, to form a posterior or occipital lobe; indeed, in these latter groups, even the middle lobe seems to be rudimentary. In the Ruminants and Pachyderms, traces of a fissure of Rolando may be detected; but in none of the preceding groups, not even in the Carnivora, excepting in the seal, is there to be found, within the cerebrum, a prolongation backwards of the lateral ventricle, in the form of a posterior cornu; in the seal, a rudimentary cornu, with its contents, first appears. It is not to be inferred from this, however, that there does not exist some small portion of the cerebral hemispheres of these animals, which is anatomically and physiologically homologous with, or representative of, the parts called the posterior lobes in the still higher Mammalia, and in Man; but all we are entitled to say is, that the plan of structure of the hemispheres, excludes such subdivisions or markings, as serve to distinguish a part, as a posterior or occipital lobe. In all the so-called Quadrumana, however, which amongst the Mammalia are nearest to man, and which, as we have seen (p. 126) have been zoologically associated with him, in a common Order, named Primates, another plan prevails, in the arrangement of the substance of the cerebral hemispheres, which indeed corresponds fundamentally, with the plan observed in the human cerebrum. It is one part of this plan, that the existence of a posterior or occipital lobe, should be indicated internally, by the extension backwards, into that part of the hemisphere, of an included prolongation of the lateral ventricle, forming a distinct posterior cornu; besides this, when traces of fissures appear upon the surface of the hemispheres, they occupy the position of the principal fissures of the human brain, viz., the fissure of Rolando, marking off the frontal from the parietal lobe; the internal perpendicular fissure, distinguishing, even on the surface, the occipital, or posterior, from the parietal, or middle, lobe; and the fissure of the hippocampi, formed by the folding inwards of the cerebral substance, along the floor of the posterior cornu. In the higher monkeys, the baboons and the anthropoid apes, other sulci appear between the principal fissures, serving, step by step, to complicate the cerebral surface, and to mark it off, into more and more numerous convolutions, the general

arrangement of which, is undoubtedly correspondent with that traceable in the far more complex array of convolutions in the human brain. In all these, there may be recognised certain primary frontal, parietal, occipital, and temporal convolutions, which have, as in the Ruminant and Carnivorous brains, a general longitudinal direction ; and, in the higher forms, secondary convolutions are interposed. Both the primary and secondary convolutions become progressively more tortuous ; and certain of the latter are met with only in man. It is beyond doubt, however, that the cerebrum of the so-called Quadrumana, and that of Man, are constructed on a common plan ; but when we consider its absolute size, or, more especially, its relative size, as compared with the cerebellum, the spinal cord or the entire body, the relative development in particular of its frontal and parietal regions, furthermore, the number and complexity of its secondary convolutions, and lastly, the thickness of its grey matter, and the amount of its commissural fibres, there exists an enormous difference between the cerebrum of man, and that of the highest anthropoid ape. There is not, indeed, in these respects, so great a difference between them, as exists between the lowest and the highest of the so-called Quadrumana ; but there is a vastly greater difference than is found between the brains of any two quadrumanous species, or even between the brains of the *different genera.* Recent researches on this subject, whilst they have served to show a closer affinity, than was before believed to exist, between the Quadrumana and Man, still leave a wide and unbridged chasm between them ; nor do geological researches yet offer any intermediate and progressively approximating cranial forms.

Of the several plans of the cerebral convolutions of the Mammalia, thus briefly sketched out, it is difficult, at present, to say that the Pachydermatous and Ruminant plan is necessarily inferior to the Carnivorous plan ; but there can be no doubt, that this latter is decidedly lower than the plan observed in the Primates, which include the so-called Quadrumana and Man.

In regard to the relative *complexity* of different brains within each plan, a very general rule has been observed (though exceptions to it have been pointed out), viz. that the cerebral hemispheres are more convoluted in the larger species or genera of any great group of the Mammalia, than in the smaller species or genera of such groups. For example, this is true successively of the larger as compared with the smaller Quadrumana, as seen in the orang, the baboons, the monkeys, and the lemurs ; of the larger and smaller Carnivora, as in the seal and the cat ; of the larger and smaller Pachydermata, as in the elephant, horse, and pig; of the larger and smaller Ruminants, as in the ox and sheep, and so on. The case of the elephant is perhaps the best single known illustration of the striking relation between the size of the body and the complexity of the cerebral convolutions, which are singularly numerous and tortuous in that large animal. They are also very complex in the somewhat allied, and usually bulky, Cetacea. As an exception to the general rule, it is stated, that the brain of the horse, is less complicated than that of the ass, although the former animal is larger; but the pony's brain is certainly more complex than the donkey's. Again, the brains of the lion and cat, notwithstanding the difference in size between their bodies and their brains, also present none in the degree of complexity of their cerebral convolutions. It has been suggested, that the relatively more convoluted cerebrum of

the larger species, is to enable the necessary amount of grey matter to be contained in a cranium of a given size, otherwise, the head would have been inconveniently bulky (Dareste); but this is probably not the whole explanation, or there would be no exceptions. Besides this, the cranial cavities of the elephant and whale, are not nearly so large as their heads would allow. However, it has been shown, that, although the effect of the convolution of the surface of the cerebrum, is to increase largely the quantity of grey matter, yet the size or weight of this organ, by no means increases, *pari passu*, with the complication of its surface; for, in proportion to its surface, which is so highly convoluted, the cerebrum of man is only two-and-a-half times as large as that of the rabbit, the surface of which is quite smooth (Baillarger): the larger quantity of medullary commissural fibres in the superior brain, accounts for this.

In brains still more simple than those of the lowest Mammalia, not only are there no convolutions, but neither external nor internal distinctions into lobes. A few symmetrical lines only, are traceable in Birds, but none whatever in Reptiles, Amphibia, and Fishes. The so-called cerebral lobes, or rather their superficial layers, in these four oviparous classes of Vertebrata, are by some, indeed, supposed to represent the anterior lobes only, of the hemispheres of the cerebrum in the Mammalia; first, from the absence of the corpus callosum, and secondly, from their connection with other parts. The middle lobes are believed to appear first, in the lower Mammalia, and afterwards, the posterior lobes in the higher forms. But, as already intimated, the lobes may not be distinguishable, and yet homologous parts of the cerebral hemispheres may be present, however slightly developed, throughout all the Vertebrata.

Amidst the known varieties of plan, and all the degrees of complication of the cerebral convolutions within the limits of each plan, one particular feature seems to be of considerable importance, in estimating the relative superiority of any given brain. We allude to the degree of symmetry of the convolutions of the two hemispheres. In the simple, diminutive hemispheres of the Fish and Reptile, even in the more highly developed, and slightly sulcated, hemispheres of certain Birds, and in the smooth cerebra of the Monotremata and Marsupialia, and of the lower Rodentia, and the lemurs, the symmetry of form is apparently exact. As soon as any markings appear on the hemispheres, and even when these are tolerably numerous, as in the Carnivora and more highly developed monkeys, they are very symmetrical on the two sides; but in the more complex brains of the larger Pachydermata and Ruminantia, especially in the horse and elephant, and also in the still more highly developed brains of the anthropoid apes, a certain want of symmetry becomes apparent. But it is in the human brain more particularly, that exactitude of symmetry disappears. In fact, the extraordinary relative size of the cerebral hemispheres, the number of its secondary convolutions, and the absence of symmetry in the forms and dispositions of all the convolutions, constitute the three great external distinguishing characters of the human brain.

If, finally, we regard the general plans, and the secondary arrangements, of the cerebral hemispheres in the different Vertebrata, from a physiological point of view, we find a close general correspondence between the amount of intelligence manifested by the several members of this series, and the degree of complexity of the cerebral hemispheres. It has even

been noticed that, in different varieties of one kind of animal, subjected to different conditions, as regards education, and therefore exhibiting various grades of active intelligence, the general development and size of the cerebrum, keep pace with the growth of that intelligence; for the brains of trained and domesticated dogs, are proportionally larger than those of the wild dog. But hitherto, the attempts made by psychologists and comparative anatomists, to associate, with certainty, particular parts of these hemispheres, with particular psychical endowments, have proved abortive.

The ganglionic masses at the base of the cerebrum.—The *corpora quadrigemina* are still divided, as their name implies, into four eminences throughout all the Mammalia; the anterior pair are larger in the Herbivora, and the posterior pair in the Carnivora. In Birds, Reptiles, and Fishes, these bodies are *bigeminal,* consisting of only a single pair of tubercles, or ganglionic masses, which are closely attached to the optic thalami, and form the so-called *optic lobes*; in the osseous fishes, these optic lobes include the optic thalami, or supposed centre of common sensation. The *corpora striata* are always, throughout the whole of the Vertebrata, as in man, concealed by the cerebral hemispheres; but as these latter parts are more and more reduced in size, the striated bodies become more and more apparent, and at last, in the Fishes, constitute, almost alone, the so-called *cerebral lobes,* a very thin layer of grey matter, forming the only remnant, or representative, of the cerebral hemispheres. In Birds, and in the higher cartilaginous fishes, a ventricular cavity, into which the striated bodies project, is found in these cerebral lobes. It has been suggested, that not only consciousness of simple sensations, but their perception, or the reference of these to their proper external objects, is accomplished in the sensorial ganglia at the base of the cerebrum, at least in these lower Vertebrata (Carpenter); but this view is hypothetical. The size of the optic, and also that of the olfactory lobes, varies in different groups of animals; thus the *olfactory lobes* are larger in animals which possess an acute sense of smell, as in certain Carnivora, in the Ruminantia and Rodentia, and even in the shark tribe amongst Fishes; whilst the *optic lobes* are very large in Birds, animals in which the sight is very powerful, and also in certain Fishes.

Structure of the Cerebrum.—The internal structure of the cerebral hemispheres, also undergoes simplification in the descending vertebrate series. As we have seen, the *lateral ventricles* become smaller in extent, and of simpler form, their posterior cornua being absent, except in the seal, in animals lower than the Quadrumana. The thickness of the *grey matter* of the hemispheres, also gradually diminishes, in passing from the higher to the lower Vertebrata. The layer of cortical substance in Fishes, is so thin, that these parts of the encephalon appear almost white to the naked eye. It is obvious, that the numerous layers distinguishable in the cortical substance in man, and which have also been seen in the Mammalia, must gradually become fewer, and at last disappear. The quantity of *medullary substance,* although proportionally to the grey matter greater, is also absolutely diminished, and the arrangement of its fibres becomes much simplified. This appears especially to be the case as regards the fibres, which, in the higher brains, pass from one set of convolutions to another set, or, in the smooth brain, from one part of a hemisphere to the other. So, too, a very significant diminution takes

place in the number of the transverse commissural fibres which serve to unite the right and left halves of the cerebrum, and to bring their respective bilateral parts, into physiological connection. The *corpus callosum*, for example, which, in the brain of man, and in that of the higher Mammalia, is of such great extent and thickness, and contains the chief part of these transverse commissural fibres, has been shown to be relatively smaller, even in the highest anthropoid apes, than it is in man. Speaking generally, when examined in a median section, it becomes shorter from before backwards, and thinner, and, gradually losing its horizontal position, is inclined upwards and backwards in the lower Mammalia; in the Rodents it becomes very short and thin, and nearly vertical. In the Marsupialia, it is so rudimentary, and so limited to the anterior part of the fissure between the hemispheres, as to have been described as absent, there being no transverse bridge of cerebral matter, connecting the two hemispheres above the ventricular cavities; there exists, however, a compact transverse commissural mass, situated at the anterior part of the base of the brain, and besides this, the so-called anterior commissure is largely developed. In no Vertebrate animal lower than the Mammalia, is there any trace of a corpus callosum, but there are merely transverse commissural fibres, crossing at the base of the cerebrum, as is seen in Birds, Reptiles, Amphibia, and Fishes. In the Mammalia, its size, and its development backwards, are exactly proportional to the size, and extension backwards, of the cerebral hemispheres, until they even overlap the cerebellum, as in the Quadrumana and in Man.

The gradual simplification, in the number and connections of the white fibres of the cerebrum, must involve a less perfect physiological co-operation, or combination of actions, between its several parts; and it is obviously associated with retrogressively inferior psychical endowments. But the facts of structure, and the observations on the powers and characters of the lower animals, which might throw light on the special physiology of the cerebral hemispheres, remain for future inquirers to collect.

The Cerebellum.—Like the cerebrum, the cerebellum gradually diminishes in size, as compared with the spinal cord, or with the weight of the body, in passing from the highest to the lowest Vertebrata; though, if compared with the cerebrum, it is larger in many of the lower Vertebrata than in man, owing to the extraordinary development of the cerebral hemispheres in him. The principal anatomical feature of the highest forms of the cerebellum, is the great development of its lateral masses, or *hemispheres*, which, however, are still proportionally very large in the Quadrumana. Considered generally, the lateral parts diminish rapidly in the lower Mammalia, until, at last, they are represented only by the small portions named the *flocculi*. In Birds, the hemispheres are represented by still smaller lateral appendages, the great bulk of this organ, in them, being evidently composed of the *central lobe* or *vermiform processes*; whilst in the Reptiles, Amphibia, and Fishes, this median portion is alone present, so that it would seem to be more fundamentally important than the superadded lateral parts or hemispheres.

The structure of the cerebellum, as well as its size, become also progressively simplified. The number of its laminæ diminish, until at last, as in the Birds, they are comparatively few; whilst, in the Reptiles

Amphibia, and Fishes, its surface is commonly quite smooth, but still, however, consists of a thin stratum of grey matter. In the frog, the cerebellum forms a simple smooth curved band; and in the lowest Fishes, it is reduced to a thin layer of nervous substance, too small to conceal the back of the medulla oblongata; but in some cartilaginous Fishes, as in the sharks, for example, the otherwise simple median cerebellum is slightly notched, or laminated, upon its surface. In certain Mammalia, as in the Carnivora and Ruminantia, the cerebellum, instead of consisting of broad and comparatively smooth lateral hemispheres, joined by a narrow median and much divided portion, or vermiform process, is very uneven upon its surface, apparently consisting of a cluster of many irregular and deeply foliated lobules.

The internal structure of the cerebellum, also becomes simplified, in accordance with the gradual diminution in the number of its laminæ; so that the appearance, on a section, named the *arbor vitæ*, ceases to be distinguishable. The *corpora dentata* exist in all Mammalia, but they are less plicated, and, in the lowest forms, present on a section a smooth outline; they have not been seen in the oviparous Vertebrata.

Physiologically considered, the size and complexity of structure of the cerebellum, appear to be in harmony with the degree of complication of the movements capable of being executed by any given animal; for example, it is relatively larger, in the apes and monkeys, than in the Carnivora, and larger in these, than in the Ruminants or Rodents; it is also larger in Birds than in Reptiles; and it is larger in the active predaceous sharks, which can turn themselves round and round, and even swim sideways in the water, than in the ordinary and more simply swimming fishes. Again, in comparing individual genera of the same Order, this organ is more developed in the Anthropoid apes, than in the monkeys, the former being able to assume a more manlike attitude than the latter; and it is also larger in the bear, which can temporarily assume an erect posture, than in the dog. In Man, in whom the cerebellum reaches its highest development, besides the innumerable and complex movements of the upper limbs, the co-ordination of the multitudinous individual motions, necessary to preserve the equilibrium of his erect body, in standing and walking, is much more perfect than that required in the quadruped form of locomotion; and, again, in Birds, in which the cerebellum is still more simple than in Mammalia, the movements of the wings are also more simple, employ but few muscles, are maintained for a long time without fatigue, and exhibit rather an automatic than a volitional character, as shown by the attempted flight of birds when deprived of their cerebrum, or even when decapitated.

The pons Varolii.—In proportion to the gradual diminution of the cerebellum, especially of its lateral parts or hemispheres, the pons Varolii becomes diminished in size; and when the hemispheres are reduced to insignificant appendages, as in Birds, or are absent, as in Reptiles, Amphibia, and Fishes, the pons does not exist, a fact which indicates the physiological use of the pons, to be to establish functional relations between the two hemispheres of the cerebellum.

The Medulla Oblongata and Spinal Cord.—The medulla oblongata also shares in that gradual simplification, which is observed in the rest of the encephalon, in the descending series of the Vertebrata. The first parts to become diminished, and then to disappear, are the *olivary bodies,*

their *corpora dentata* and the columns of white matter connected with them, these parts not being distinctly present below the Mammalia. The anterior and posterior pyramids, and the restiform bodies, accordingly gradually preponderate, and finally constitute the entire mass of the medulla oblongata, the size of which, presents a general correspondence with that of the body of the animal, and becomes larger, in proportion to the cerebrum, in the descending vertebrate scale. The triangular depression formed, on its posterior surface, by the divergence of the restiform bodies, becomes plainer in the lower animals, and is more directly continuous with the central canal in the spinal cord. In certain Fishes, the two halves of the medulla, are actually separate from each other, leaving an oblong opening in the middle line, which has been compared, though incorrectly, with the ring or collar of nervous substance, which surrounds the œsophagus in the Mollusca and Annulosa; for the œsophagus never perforates this divided medulla oblongata, even in the lowest fishes.

The spinal cord likewise exhibits signs of simplification. Its two enlargements, cervical and lumbar, are present in all the Vertebrata which possess well developed anterior and posterior limbs. In most of the Mammalia, the lumbar enlargement is of greater size than the cervical enlargement. But amongst Birds, those which are remarkable for their powers of flight, like the eagle, have the cervical enlargement larger than the lumbar; whilst, in the cursorial or running birds, as in the ostrich, the reverse is the case. In the limbless Ophidian Reptiles, and also in the Fishes, the pectoral and abdominal fins, or limbs of which are so small, and have such minute muscles, both these enlargements are entirely absent, and the cord is of uniform diameter, or finely conical, gradually increasing from its lower end upwards. The extent to which it descends within the spinal canal, is greater in the cold-blooded Vertebrata generally, than in Mammalia and Birds. In certain Fishes, in which the body is very short, the cord is equally concentrated, and the cauda equina is very long. In a few rare Cyclostomatous fishes, as Orthagoriscus and Trigla, the cord presents numerous constrictions, which give it a beaded appearance, and prove the real segmented character of the spinal nervous axis, which, in the Vertebrata generally, is masked by the even fusion of its parts.

It would seem, that in certain vertebrate animals, as distinguished from man, more of the longitudinal fibres found in the spinal cord, are commissural between its several parts, or else are concerned in connecting the roots of the spinal nerves with its own grey matter, whilst fewer ascend, from the nerves, to the sensorial centres at the base of the cerebrum; this has been shown at least to be the case, in regard to the spinal cord of the horse. (Volkmann, Kölliker.) In accordance with this, the locomotive movements of such animals, are either consensual, or sensori-motor, or, as in those very low in the vertebrate scale, even purely excito-motor, becoming thus gradually less dependent on, or wholly independent of, sensation; less associated with ideas of purpose, less influenced by education, and at last, perhaps, purely automatic, and wholly dependent on the internal structure of the nervous apparatus contained in the spinal system. In the higher Mammalia, and in man, however, the locomotive movements are, to a greater extent, guided by sensation, and are commonly regulated by proper cerebral, or mental processes. It has further been

observed, as the result of section of the cord, that, in Birds and Reptiles, the decussation of the paths of sensation in the cord, is less direct, and less perfect, than in Mammalia. In the Amphibia, as in frogs, the movements performed, through the spinal cord, in the decapitated animal, are so purposive, that they simulate the volitional acts of the higher Vertebrata and of man, but their marked uniformity justifies the denial to them, of any volitional quality, a view also supported by analogy, which is opposed to the supposition that psychical endowments can be manifested by the spinal cord, in some Vertebrata, and not in others.

The Cranial and Spinal Nerves.—The cranial nerves, in the Vertebrata generally, correspond in arrangement, general distribution, and function, with those which we have described in man; but in certain cases, some of them are absent, whilst others may have a more extensive, or a more limited, distribution and office, than they have in man. For example, the olfactory nerves are absent in certain Cetacea; and the optic nerves are wanting in the Mole, and in the blind Fishes found in perfectly dark subterranean caves, as in those of Kentucky. Again, the hypoglossal nerve is more complete in the cat, ox, and rabbit, than in man, for it has a posterior root, with a small ganglion upon it, and so resembles exactly an ordinary perfect spinal nerve. On the other hand, this nerve becomes very small in certain animals, such as Birds, in which the tongue is but slightly developed; and it is still smaller in Fishes, in which it may be ranked with the spinal nerves. In certain fishes too, the fifth pair of nerves has an unusually extensive distribution, sending, in particular, a large branch, the so-called great *lateral nerve*, down the whole length of each side of the body. In Fishes, also, the vagi or pneumogastric nerves, although they no longer supply lungs, nevertheless send branches to the substituted respiratory organs, the gills.

The Sympathetic Nervous System.—The sympathetic nerve is well developed in all the Vertebrata, and is constructed on the same plan as in man, consisting of a double ganglionated cord, communicating at numerous points, with the cranial and spinal nerves, and giving off branches forwards, on which prevertebral ganglia are found, and supplying all the viscera, its ultimate twigs spreading out on the coats of the small arteries. Its offices are doubtless the same as in man; for it presides over the lowest, or vegetative, system of functions.

The Nervous System of the Amphioxus or Lancelet.—This little animal, which is the lowest Fish, and therefore stands at the bottom of the whole Vertebrate series, is so remarkable, as here to deserve a special notice. It is found principally in the Mediterranean, on the coast of Italy; but it has been, though rarely, caught in the Atlantic, and even as far north as the British seas. It is an oblong transparent animal, about three-quarters of an inch in length, blunt at its anterior, and pointed at its posterior extremity, slightly flattened at its sides, and provided with a thin marginal fin, extending along the whole back and tail, and as far forwards beneath, as the abdomen. It has a simple, short, alimentary canal, and a series of slit-like branchial openings at the sides of the pharynx, fringed with gill-like processes, constituting the respiratory apparatus. It has no distinct heart; but presents, instead, a series of contractile dilatations of the larger blood vessels, at the sides of the branchial apparatus. The nervous system, which we have here chiefly to consider, is composed

of a spinal *cord* lying in a spinal canal, above a soft central axis or column, composed of numerous thin discs arranged longitudinally, and forming a true *chorda dorsalis*, or *notochord*. This establishes the vertebrate character of this singular animal. The spinal cord extends along the whole length of the chorda dorsalis; it is thickest in the middle third, pointed behind, and presents anteriorly only a slight bulbous *cephalic enlargement*, but no distinction of parts, like corpora striata, optic thalami, or corpora quadrigemina, much less a separate cerebellum, or cerebrum, and, so far as is known, no folding over of nervous substance, to form a cavity or ventricle. From the sides of the cord, about fifty-five or sixty pairs of nerves are given off, not by double, but by *single* roots. The first pair of nerves, exceedingly minute, supply the membranous parts of the mouth. The second pair give off long dorsal and ventral branches, which run backwards nearly the whole length of the body, joining the extremities of the anterior and posterior branches of the other spinal nerves. There are no distinct olfactory nerves, but there exists a median concave *ciliated spot*, in close connection with the fore part of the cephalic bulbous enlargement, which is believed to be the organ of smell; the optic nerves are represented only by two short processes, at the end of which, is some pigment and a transparent body, thus forming two simple eye-spots; no auditory apparatus or nerve has been detected. The first pair of nerves, just now mentioned, have been considered functionally to represent the fifth cranial, and the second pair the pneumo-gastric nerve. The spinal cord consists almost entirely of nerve-cells of a spherical form; they are disposed in a linear manner, in the middle third of the cord, but elsewhere, they have an irregular and perhaps segmented arrangement; pigment exists in some of these cells. The white nerve fibres are indistinctly tubular. No trace of a sympathetic system has been yet described in the Amphioxus. Had not so simple a form of the vertebrate cerebro-spinal nervous system been actually seen, it would have been difficult to suppose its existence. One is naturally tempted to compare it with the nervous system of animals still lower in the scale, especially with that of the Annulosa. But the homologies between it and them, are not easily traceable; however simplified, the fundamental plan of its construction follows a different type; the œsophagus does not perforate its anterior portion, and a chorda dorsalis runs between it and the perivisceral or body cavity. This singular animal is not a connecting link between the Vertebrate and the Annulose types. By some, it is considered possible, that it is an embryo condition of a higher form of fish; and, until its development and subsequent life have been investigated, it may be permitted to doubt the specific character of this highly interesting and apparently archetypal animal.

On examining physiologically, the actions of animals lower in the scale than the Vertebrata, the proper psychical faculties entirely disappear, as well as the distinct cerebro-spinal form of the nervous system. The anatomical arrangements of the nervous system, in the several lower sub-kingdoms, are given in the chapter on the general characters of those sub-kingdoms (pp. 126–131). In even the highest of these non-vertebrate creatures, as in the higher Mollusca and Annulosa, the cerebral *hemispheres*, properly so called, are probably no longer represented, although

the *cephalic* ganglia of these animals, are frequently designated *cerebral*. In all the non-vertebrate forms of animal life, intelligence, emotion, and even ideation are wanting; a feeble perception, and volition, may exist in some of the so-called social insects, viz. in the wasps, bees, and ants; but sensation is their great guiding principle. The so-called *Instincts*, which are really the outward expression of *sensori-motor impulses* excited within their nervous apparatus, assume the control of all their acts, even when these, as in the case of the social insects, seem, to us, to be adapted to new or unusual conditions of existence. Intelligent acts, characterised by improvability through experience, by the varying adaptation of means to ends under altered conditions, and by the use of different means, to accomplish at will the same ends, are now replaced by instinctive acts, exhibiting a sameness, in all individuals of the same species, at all ages, and under the same conditions, as well as a uniform perfection, quite irrespective of previous trial, experience, or education. These instinctive acts are performed through the agency of a sensori-motor nervous apparatus, duly stimulated, and physiologically homologous, if not anatomically so, with the sensori-motor ganglionic nervous centres and accessory nerves, found in the Vertebrata. The cephalic ganglia of the non-vertebrate animals, constitute the sensorial centres, and represent functionally, therefore, the sensory parts of the vertebrate cerebrospinal axis; whilst excito-motor ganglia, few or many in number, as the case may be, together with the commissural cords connecting them with the cephalic ganglia, represent functionally, the medulla oblongata and the spinal cord. The anatomical homologies of these parts, are not yet accurately determined. It has, however, been argued, that not only are the cephalic ganglia of the non-vertebrate animals, the *sensorial centres*, the seats of conscious sensation, and therefore of the instinctive sensori-motor impulses, but that, to a certain extent, in the highest forms, they must exercise not only the faculty of perception, in the recognition of the relations between the images produced in the sensorium, and the external objects which cause them, but also an imperfect form of volition; otherwise the lives of these beings, must be passed, without their experiencing anything more than mere bodily pleasure and pain, and they could not exhibit that feeble manifestation of will, which they display in the selection of materials for building purposes, in their search after food, and for the companionship of their own species. Besides the sensori-motor acts and apparatus, there exist also in these animals, in very great perfection, excito-motor parts of the nervous system, by means of which, many of their movements, particularly those of locomotion, complicated as they are in many species, especially in the case of Insects and Myriapods, are essentially governed, not only without volition, but often even without conscious sensation, as a guide, as is proved by experiments to be presently mentioned; such movements are performed, in the higher examples, through the intervention of those ganglia and nerves, which correspond functionally with the *medulla* and *spinal cord*, although, as just stated, the anatomical homology between them, is not so evident. Lastly, certain portions of the nervous centres and nerves, are undoubtedly concerned in the regulation of the nutritive or vegetative functions, sometimes, perhaps, acting indirectly through the vascular apparatus, but sometimes directly, on the nutritive processes themselves. Corresponding in function, with the *Sympathetic* system of the Vertebrata, these parts in the lower animals, are but

slightly developed, and are only seldom, as in Insects, distinguishable from the rest of the nervous system, and, even then, cannot be compared anatomically, with the vertebrate sympathetic nervous system.

We may now briefly consider the functions of the different parts of the nervous system, in the several non-vertebrate sub-kingdoms.

Mollusca.

The *cephalic* ganglia, consisting, in the typical forms, of the supra-œsophageal and sub-œsophageal ganglia, sometimes also including a distinct buccal ganglion, and, in the Cephalopods, other ganglionic masses connected with the olfactory and optic nerves, receive all the nerves of special sense, which may be present in any one case, and probably also those of common sensation, and thus constitute the central sensorium, both special and common; they are analogous to the sensorial ganglia at the base of the vertebrate cerebrum; they are sometimes named cerebral, and are the only parts which can be so regarded. It is believed, however, that the cerebral hemispheres are not here represented; but, at the same time, any perceptive powers, or will, which the higher Mollusca exhibit, must be manifested by virtue of these cerebral ganglia. They receive branches from all the other ganglia, including the pedal, and parieto-splanchnic, an arrangement which probably enables them to receive impressions, calculated to excite their *sensori-motor* channels of action, and to regulate the movements of all parts of the body. In the Lamellibranchiate Molluscs, which are acephalous, there are no cephalic organs of special sense, the chief ganglia are quite simple, small, and placed near the mouth, and the movements exhibit no volitional character. In not even the highest Molluscs, can we imagine that memory, emotion, or intelligence exist.

The *pedal* ganglia, usually forming only a single pair, but, in the Cephalopods, much subdivided and scattered, are probably excito-motor nervous centres, and purely reflex; they govern many of the locomotive acts, and represent one of the segments of the spinal cord of the Vertebrata. The surface of the so-called foot, may be stimulated through impressions on afferent nerve-fibres, and these may excite the reflex motorial impulse, through the pedal ganglion and its efferent fibres. Like the spinal acts in the Vertebrate animals, these reflex locomotive movements in the Mollusca, are, however, subjected to the control of the cephalic ganglionic centres, which, through the longitudinal commissural fibres, exercise a consensual, if not a weak volitional influence over them, as in the spontaneous search after food. The locomotive acts of these creatures, are all sluggish, but more or less concatenated. It is remarkable, that the auditory organs of the Mollusca, where they exist, are usually attached, by their nerves, to the pedal ganglia; but the nerve fibres probably run on, past these ganglia, to the cephalic sensorium.

Lastly, the *parieto-splanchnic* ganglia, usually forming a single pair, but sometimes more numerous, supply not only the sides of the body and mantle, but also the respiratory organs (usually branchiæ), and the heart, as well as the digestive viscera; it is by these, that the movements of deglutition and respiration, are governed, and that the action of the heart, is regulated or influenced. But these ganglia are also placed under the control of the cephalic ganglia, especially by commissural bands,

which join the cords running on the sides of the œsophagus, from the supra- to the sub-œsophageal ganglionic masses; hence, these cords, with the parieto-splanchnic ganglia, are said to represent functionally, the tracts of the medulla oblongata. These ganglia probably serve as centres for any sympathetic nerve fibres, which these animals may possess.

Molluscoida.

These are simplified Molluscs, and the single ganglionic mass, which constitutes their chief nervous centre, is probably at once, feebly sensory, sensori-motor, and reflex. It represents the three kinds of ganglia in the Mollusca; it sends nerves to a ciliated sac, believed to be a sensory organ, and sometimes has a pigment mass or supposed eye-spot upon it; it also supplies branches to the tentacles in the Polyzoa, and others to the body and viscera. In position, and connections, however, it rather resembles the pedal ganglion of the Mollusca, and, like it, its office is essentially excito-motor or reflex. The locomotive acts of these animals, are extremely limited, most of them being fixed, or merely borne about in the sea; the most active motions which they present, are those of the sides of the body, intended to aid in the drawing in, and expulsion, of water for the purposes of respiration.

Annulosa.

The nervous system of these animals might be compared with that of the typical Mollusc, by supposing the pedal ganglia of the latter to be multiplied by the addition of numerous other pedal ganglia behind them, according to the number of segments in the Annulose animal; or, in other words, the Molluscous nervous system is like that comprehended in the cephalic and second pair of ganglia of the Annulosa. But the sympathetic system here receives a peculiarly diffused development.

The functions of the *cephalic*, or *supra- and sub-œsophageal* ganglia in the Annulosa, are also precisely similar to those of the Mollusca, being sensory, sensori-motor, and, in the higher or social insects, perhaps feebly perceptive and volitional. With these, are connected the optic nerves, which are, for the most part, very large in the Insecta and Crustacea, in correspondence with the highly developed eyes of these animals; also the smaller nerves from the antennæ or organs of touch, and from the antennules, supposed to be the seat of the sense of smell; the nerves of the auditory organs, where these exist, and however distant they may be from the head; and lastly, the nerves of common sensation, from all parts of the body and limbs. Afferent and efferent fibres, likewise, end in, and spring from, these ganglia, proceeding to the head, the segmented trunk, and the limbs, and officiating in the various and extraordinary consensual, instinctive movements exhibited by the highest of these animals, especially by the spiders, ants, and bees, in the construction of their webs, nests, and cells, and in the volitional acts implied in any special movements, particularly when they are subjected to unusual or opposing circumstances.

The series of ganglia, peculiar to these animals, which are connected together, forming the *double ganglionated cord*, found on the abdominal aspect of their segmented bodies, are the locomotive ganglia, corresponding, in function, with the pedal ganglia of the Mollusca; they constitute the excito-motor reflex centres for the locomotive acts, which, in these

animals, as in the various insects, spiders, and myriapods, and even in the swimming crustacea, are probably essentially automatic, and performed independently of sensation, though they may be associated with it, and are independent of volition, although they may often be controlled by it. The ascertained structure of this ganglionated nervous cord, corresponds entirely with these combined functions ; for some of the fibres of the roots of the nerves, which arise from it, are seen to end in the grey matter of the ganglion of their own segment, or to pass out at the opposite side or at the same side, often becoming, as demonstrated in the leech, connected with processes from the nerve cells ; other fibres pass from the nerves of one segment, up and down, along the cord, through one, two, or even three adjacent ganglia, and then pass out into as many corresponding nerves of the same or of the opposite side, above and below ; other fibres, proper to the cord, act as short longitudinal commissural fibres, uniting the ganglia of adjacent segments, and joining the first ganglionic masses to the cephalic ganglia, those cords which pass by the œsophagus, being compared to the medulla oblongata; lastly, fibres are met with, sometimes named *transcurrent*, which pass over the several ganglia, and form longitudinal tracts, extending upwards to the cephalic ganglia. By these last named fibres, all parts of the system are brought into subjection to the chief or cephalic apparatus; whilst, within itself, every segment, with its ganglion and nerves, can act, either independently, or in combination with other segments. These anatomical facts present a sort of analysis of the arrangements believed to exist in the more complex spinal cord of the Vertebrata, which is supposed to consist of independent centres, fused together by continuity of the grey matter; functionally and structurally, we here recognise a homology, though, as already mentioned, there is, as yet, no evidence that the double ganglionated cord of the Annulose type, is the anatomical homologue of the spinal cord of the Vertebrate type. Experiments have demonstrated most conclusively, that this part of the nervous system of an Annulose animal, consists of independent and purely reflex centres ; and that they yield phenomena precisely similar in character to, but even more striking than, those presented by lizards, frogs, and newts. Thus, a decapitated insect, nay, even a single segment of a centipede, continues to perform symmetrical and characteristic movements when it is irritated, or placed in such a position as to be stimulated to action ; a water-beetle, for example, if beheaded, and then placed in water, will perform natatory movements. When, however, portions of an Annulose animal, severed from their connection with the cephalic ganglia, are left untouched, or are not subjected to any special stimulus, they remain quiescent and immovable. Moreover, though a decapitated centipede will, if irritated, continue an onward movement, and push its headless trunk against any opposing body, it will not mount over it, turn aside, or move backwards, as it would do, if still under the guidance of sensation, and a low form of volition; it cannot adapt, or suit, its movements to the nature of the obstacle, or impediment, placed in its path. The multiplied feet of these animals, demand a corresponding multiplication of the ganglionic reflex excito-motor centres, but they are made to act harmoniously, in succession, and in alternation, on the two sides, by the fibres which pass from nerve to nerve, and from one segment of the cord to another; whilst, in the perfect animal, all are brought into harmony, either instinctively cr volitionally, by the transcurrent cephalic fibres. The government

of the remarkable locomotive powers of these animals, is thus provided for, their active respiratory functions, and other nutritive processes, assisting, and giving them the requisite muscular irritability, which is so striking, when contrasted with the slow movements of the Mollusca.

Instead of the parieto-splanchnic ganglia of the Mollusca, there is found, at least in the higher Annulosa, a very remarkably complete sympathetic system. Even from the cephalic ganglia, two minute filaments are given off, which speedily unite, to form a single cord, on which a minute ganglion is found; and from this, branches proceed to the alimentary canal, the dorsal vessel, and the adjacent large tracheæ; from the commissural bands, or tracts, between the several ganglia, similar nervous filaments arise, which unite, are connected with a minute ganglion, and give off branches, chiefly for the dorsal vessel and tracheæ of particular segments. These minute ganglia and nerves must govern, like the sympathetic system of the Vertebrata, the vegetative processes of the animal, viz. those performed by the alimentary canal, the glands, the dorsal vessel, and the tracheæ.

The nervous system of the Annulosa, is modified, so as to be adapted to the varieties of form in the heads and bodies of the different Classes or groups. Thus, the development of the cephalic ganglia, corresponds exactly, with that of the parts situated on the head, and of the organs of the senses, especially of the eyes. Again, the number, size, and degree of concentration, of the series of abdominal ganglia, correspond with the number of the segments in the body, their size, the degree of development of their attached limbs, and the mode in which, two or three segments are sometimes fused together. In the tailed Crustacea, as in the lobsters, shrimps, and others, the thoracic segments are consolidated, and the thoracic ganglia are concentrated into a single large mass, placed at a considerable distance from the cephalic ganglion, the connecting commissures between which, are therefore unusually long; this thoracic ganglion supplies the nerves to the claws and feet; the abdominal ganglia, in accordance with the length and subdivisions of the trunk, are numerous and separate. On the other hand, in the tailless Crustacea, as in the crab tribe, in which the body is mainly composed of the wide and consolidated thoracic segments, and the abdomen is, as it were, atrophied, the nervous system consists of a cephalic ganglion, placed in the head, and connected, by the usual commissural nerve cords, with a single thoracic ganglionic mass, in which, all the locomotive ganglia are concentrated, and from which, the nerves radiate to the several feet; in this most perfect example of the concentration of the inferior ganglia, the resulting nervous mass may be aptly compared to a Molluscous pedal ganglion. In the Arachnida, or spiders, the inferior portion of the nervous system, is also remarkably concentrated, there being usually a large thoracic ganglion, and a large single abdominal ganglion. Finally, in the Myriapoda or Centipedes, the nervous system, in accordance with the repetitive segmentation of the body, the number and equality of its component segments, the absence of any specially developed locomotive members from any one segment, and the presence of numerous members of nearly equal development upon all the segments of the body, presents a great number of abdominal ganglia, a pair being found in each segment of the trunk, differing but little in size, one from the other.

Most remarkable instances of the pliability of organic types, may be

seen in the singular modifications of the nervous system of the same individual insect, during the metamorphosis which the true insects undergo, from the larva or caterpillar state, to the pupa or chrysalis, and then to the imago state. In each of these changes, the nervous system participates. Thus, in the caterpillar, or grub, in which the segments of the body, are always more numerous than in the perfect insect, the number of the abdominal ganglia is increased accordingly; and, as these several segments, in the caterpillar, are of nearly equal importance, and equally developed, the ganglia are of nearly equal or uniform size. Moreover, as the organs of special sense, of which the eyes are still the most important, are comparatively feebly developed, the cephalic ganglia or special sensorial centres, are relatively small, and present no marked preponderance over the abdominal ganglia. The locomotive powers of the caterpillar, or grub, are also singularly limited, in comparison with those of the perfect butterfly or beetle; and such combining and controlling power, as is necessary to bring the locomotive movements into harmonious action, is, of course, of feebler character; hence the small relative size of the cephalic ganglion. In the chrysalis stage, in which preparation is already being made, for the development of the perfect insect, suitable modifications in the nervous system begin to take place; these consist, first, in a concentration of some of the longitudinal chain of ganglia, especially of those corresponding with the thoracic region, now and hereafter to be developed as the basis of support, not only of the lower limbs, but also of the wings, and containing the large muscles which move those members; secondly, in an actual wasting, or disappearance, of some of the abdominal ganglia, in accordance with changes, or abortions, of the segments themselves; and lastly, in an increase in the size of the cephalic ganglia, harmonising with the foreshadowed increased development of the sensory powers, of the sensori-motor or instinctive faculty, and of such volitional manifestations, as the perfect insect is capable of. In the perfect insect, these changes in the nervous system, attain their full development; the cephalic ganglion, the great sensory centre, and controlling motor centre, assumes a preponderating size, in comparison with the other ganglia; the thoracic pairs of ganglia are enlarged and concentrated; whilst the abdominal ganglia remain small, or even diminish in size, posteriorly.

Annuloida.

The quadruple, double, or single cephalic ganglion of the vermiform Scolecida, or Rotiferous animalcules, undoubtedly combines the sensory, and the sensori-motor powers, and the reflex faculty as well; but there is no evidence of real volition in these animals. It has connected with it, the nerves of the tentacles, and those of certain ciliated, and possibly sensory, sacs, and resting upon it, in some cases, are pigmentary eye-spots, or rudimentary ocular organs. The Rotifera, at all events, seem to be attracted by light and heat. Passing backwards from the cephalic ganglionic mass, are also nerves, which supply the skin, the muscles of the body, and even the viscera. The nervous system of the Echinodermata, is very peculiar, being adapted to the radiated condition of the body; its several ganglia may be regarded as parts of one divided cephalic ganglion connected by commissures; from its five segments, afferent and efferent fibres proceed to the rays, or divisions, of the animal, to the mouth and

viscera; the eye-spots, found in some star-fishes, also have minute nerves traceable to them. There is certainly no sign of volition in the Echinodermata; their sensation is also of the lowest order; and the sensori-motor, or instinctive, movements are probably almost entirely replaced by purely excito-motor, or reflex, acts, which would almost explain their habits and life. None of the five ganglia are larger than, or exhibit any superiority over, the rest; they may be regarded as presenting an example of a subdivided locomotive or Molluscous pedal ganglion, with but a slight share of sensibility superadded. Moreover, the ganglia are connected by some physiological, as well as anatomical, bond; for, in the Synapta, a species of star-fish, which has the habit of casting off, at its base, an injured or irritated ray, this power is lost, if any part of the nervous circle around the mouth, be previously cut through.

The functions of the sympathetic system, seem to be performed by the general nervous system, or by parts blended with it; for no distinct ganglia appear to be set aside for it.

Cœlenterata.

In the few instances, in which a distinct nervous system has been detected in this sub-kingdom, as in Beroe and Cydippe, its ganglionic central mass has a spot of pigment upon it, and gives off nerves to the soft contractile walls of the body, and to the so-called auditory sacs. It must fulfil a sympathetic and reflex office; it may also exercise the feeblest sensory or sensori-motor power; but no volitional functions. It is possible, that in the simplest forms, such as the Hydra, no nervous system exists; it is more probable, however, that it is present, but has escaped detection. Lower than this, we cannot imagine, on physiological grounds, the presence of a nervous system, which controls movement; for, without one afferent, and one efferent, fibre, and a connecting nerve cell, we cannot well understand how nerve substance can exercise any governing influence over muscular fibres, contractile cells, or sarcodous substance. Without these three elements at least, the muscular substance probably contracts by direct stimulation of its fibres, and the resulting movements would be *irregular* and indeterminate. The supposed admixture of nerve cells, with the other tissue elements, or of nervous granules with the cell contents of the uni-cellular animals, might still, however, have for its office, some feeble sensorial function, or the regulation of the nutrition of the tissues, in some manner unknown to us, but analogous to that of a sympathetic system.

Protozoa.

In this, the lowest subdivision of the animal kingdom, so far as microscopic research has extended, and so far as physiological inference may be our guide, a nervous system, consisting of nerve cells and nerve fibres, cannot exist; and the idea, already alluded to, of the presence of nervous granules in their substance, is, of course, hypothetical. The Infusoria, which are uni-cellular animals, that is, composed of a single organic cell, and which are moved entirely by the action of cilia on their surface, may well be understood to require no motorial nervous apparatus, to govern their movements, seeing that the ciliary motion, even in the higher animals, is independent of nervous influence. It is certain, however, that Infusorial

animalcules, kept in a vessel of water, will congregate towards the light; and in some of these minute organisms, coloured spots present themselves, which, if they be ocular spots, would imply some feeble form of sensation. A granule, or particle of nerve substance, situated at some particular point, within this single-celled animal, might form an excitable sensorial nerve centre, without exercising any controlling motor influence. In the Rhizopoda, or Foraminifera, and in the Spongida and Gregarinida, all of which consist of a fleshy or contractile sarcodous mass, not enveloped by any distinct cell wall, and the shape of which may, in the two former groups, change most irregularly, it would seem as if the contraction of the sarcode, on which the movements of these primitive animals depend, were excited directly by external stimuli, acting without the intervention of nervous substance. Their motions can scarcely be said to possess the spontaneity and regularity, which are characteristic of those dictated by, or excited through, a nervous system, and which therefore are characteristic of animal life. They resemble more, those performed by the parts of plants, or by some of the lower plants, in which the co-operation of nervous substance, is not even suspected.

If these lowest forms of Protozoa, possess any nervous granules within them, they are probably not even sensory, for no trace of ocular pigment is found in them ; such granules might, however, exercise a control over the nutrition of the cell, and in this way, indeed, might influence ciliary motion, not only in the Spongida, but in the Infusoria, in the Cœlenterata, and in all the higher animals, even in the Vertebrata; for that motion may be intimately connected with, if not wholly dependent on, nutritive molecular changes.

THE SENSES.

Sensation in general.

Sensation consists essentially, in a certain change in the sensorium, or the sensorial portion of the cerebrum, accompanied by the mental state known as consciousness. By this, we become aware of external or internal impressions made upon the sensory nerves, or, rather, of certain conditions of those nerves, produced by those impressions. The consciousness of these central changes, produced within us, by means of such impressions, constitutes sensation. Changes, originating in the sensorial centres, may also induce internal sensations. Hence, in the act of sensation, whether from external or internal causes, we feel the condition of our nerves and nervous centres, and not the objects or stimuli which excite them.

The ultimate evidence of the existence of sensation, in each individual, is intrinsic and personal. Conscious sensation is a fact, in the constitution of our corporeal and mental nature, which is absolutely incapable of explanation. The evidence of sensation in other persons, is a matter of inference from like-

ness of organisation, and similarity of behaviour under like impressions; or it rests on testimony as to what they feel. The sensations of others, and their identity with, or similitude to, our own, can neither be known nor demonstrated; they can only be inferred, or assented to. As regards animals, the existence in them, of sensations, whether common or special, is merely inferable, from the facts of their organisation and their conduct. Many of our ordinary sensations are composed of sensations, associated with certain ideas or judgments.

The conditions of sensation, are *anatomical*, *physiological*, and *causal*. First, there must exist a sensitive surface or organ, to which the peripheral extremities of the sensory nerve fibres may be distributed; secondly, such sensory nerve fibres; and, thirdly, a sensorial grey nervous centre; moreover, these several parts must be in anatomical connection with each other. Such parts, for example, are the eye, the optic nerve, and certain portions of the cerebrum. Even where, as in the exceedingly simple eyes of some of the lower animals, the ocular spots are placed close upon the nervous ganglia, there are doubtless extremely short connecting nerve fibres between them. Secondly, the physiological conditions of sensation, are, the healthy state of the several specially endowed anatomical organs, a due supply of arterial blood to those parts, and an active state of their nutrition; for, if they be either fatigued or inflamed, over-excited, exhausted, or atrophied, sensation is modified, or even suspended. Abnormal conditions of that part of the sensorium, which is concerned in any particular sensation, may cause increased, or diminished, sensibility to external, or internal, impressions. Lastly, the several parts, just enumerated as constituting a complete sensorial apparatus, must be excited by some causal agent, known as a *stimulus*, which, in the ordinary acts of sensation, induces a change in the nerves, and, through these, in the sensorial nervous centres, but which, in the case of internal sensations, may act, either on the nerves, or directly upon the nervous centres.

Sensory stimuli are said to be, either *external* or *internal*, according as they proceed from without, or from within, the body. The former have also been named *objective*, the latter *subjective*; but, as elsewhere already mentioned, even internal stimuli are equally *objective* in reference to the *mind*, which is, in the metaphysical sense, the real subjective element of our nature: to this, the body, and even the nervous system, and the sensorium itself, are truly objective, and stimuli proceeding

from them, are therefore likewise objective, though internal or corporeal. The ordinary *external* objective stimuli are physical, material or mechanical, chemical, thermal, or electrical, and include matter of all kinds, all forms of motion, molar or molecular, undulatory or impulsive, such as those which produce sound, heat, perhaps chemical action, light, and electricity. Such motions, succeeding each other according to fixed laws, may be supposed to be propagated onwards, through the sensory apparatus, or to produce corresponding motions, molar or molecular, in it. The *internal* or corporeal objective stimuli reside in the blood, such as its temperature, and peculiarities in its chemical composition; or they may proceed from the tissues to which the nerves are distributed, changes in the nutritive metamorphosis of which, may affect the nerves; or they may depend upon changes in the nutritive condition of the extremities, or of the trunks, of the sensory nerve fibres, or of the sensorial nervous centres themselves. The sensations resulting from such stimuli, are commonly known as *subjective*. But, as we have already mentioned, the only true subjective stimuli which can cause sensations, are those depending on purely psychical or mental states, such as ideas or emotions. It is often difficult, in regard to certain sensations, to say whether they are corporeally or externally objective; also whether they are truly subjective, corporeally objective, or externally objective. Experience and close examination, can alone decide these points. Sensory stimuli have also been defined, according to whether they are able to produce only one kind of sensation, or several different kinds, as either *homologous* or *heterologous*. For the reception of the former, such as light and sound, the sensory organ requires to be peculiarly constructed, and the nerve to be specially sensitive at its extremity. The latter, such as electricity or mechanical shocks, produce various forms of sensation, and act on all kinds of sensory organs. The sensations produced by either kind of stimulus, are similar for each organ. A homologous stimulus acts only on its proper nerve; light, for example, has no effect on the nerves of taste; moreover, such a stimulus acts only on the periphery of the nerve-fibres, and not upon their trunks, as is illustrated by the fact that the optic *nerve* itself is insensible to light. As different stimuli, acting on the same sensory organ, give rise to the same kind of sensation; and, again, as the same stimulus may produce different sensations, if it acts on different organs, it

would appear, that each sensory apparatus has its own recipient power or endowment, perhaps likewise some special energy in its nerve, and, as is generally supposed, in its proper sensorial nervous centre. Hence, an absolutely deaf person cannot hear, even the loudest sonorous vibrations; but he may perceive them, through the sense of touch, as physical vibrations of matter.

Certain general facts, in regard to sensation, have been described as laws of sensation. For example, in the ordinary act of external objective sensation, the surface of the sensory organ is the immediate recipient of the stimulus, and, through it, the first impression is made on the peripheral extremities of the sensory nerve-fibres. These latter, then, play an internuncial part, and conduct the changes induced in them, to the sensorial nervous centre, which itself undergoes changes, being the excitable anatomical seat of what is known to our consciousness, as sensation. The presence and the degree of sensibility in a part, depend, other things being equal, on the existence and the number of nerve-fibres distributed to it; thus parts and tissues destitute of nerves, such as the nails, hairs, and cuticle, are absolutely insensible; the tendons and bones, which have but few nerves, are but moderately sensitive, excepting in cases of disease; whilst the skin, lips, and tongue, are highly sensitive, being provided with an abundance of nerve-fibres. Stimuli act especially, and most easily and effectively, on the extremities of the nerve-fibres.

Each point, or definite part, of a recipient sensory surface is independent in its action, as regards all other points or parts; and so there must be corresponding points, or parts, in the sensory nervous centre: otherwise there could be no distinctness of local impression, on which depend, to a great extent, if not entirely, the accuracy of certain sensations, for example, those of touch and sight, and also the power of comparing different, or repeated similar, sensations. The independence of the nerve-fibres, in their course from the sensory organs to the great nervous centres, is supposed to account for this independence, so far as regards the internuncial nerve cords.

Another interesting general fact, concerning sensation, is, that the mind, i.e. the mental perception, refers sensations not to the sensorial centre, or actual seat of conscious sensation, but either to the stimulated part, or seat of the primary impression, or even to the outer world. Thus the prick of a pin, is at once referred to the skin, and not to the sensorial portion of the cerebrum,

where the sensation is completed; and, again, the impressions which produce the sensations of taste and smell, are also located in the tongue and nose. The sensations belonging to hearing and sight, are likewise not felt in the brain, and only appear to take place *through* the ear and eye; but they are referred exclusively, to their external causes, outside of, and more or less remote from, the body. It is also to be noted, that touch, taste, and smell, are excited by bodies of various kinds, whilst hearing and sight are stimulated, each by one special agent. The reference of sensations to the peripheral extremities of a nerve, even though this be stimulated in its trunk, is illustrated by the tingling of the little finger, or the feeling of pins and needles, when the ulnar nerve is struck, or compressed, at the elbow, or *funny bone*; and the same phenomenon is observed after amputations of the limbs, when sensations are felt, as it is expressed, in the amputated toes or fingers, owing to irritation in the cut ends of the nerves of the stump. This local reference of the sensations, to the extremity of the nerves concerned, is also exemplified in the phenomena of the transference and radiation of painful sensations (see page 345).

The nature of some sensations, as we have just shown, is so purely objective, that we habitually refer them entirely to the outer world, without being conscious of any internal or local changes in the sensory apparatus; this is the case in sight and hearing. A less completely objective sensation is that of pressure, since we refer it to a part of the body, as well as to its external cause. Still less apparently objective sensations are smell, taste, and the thermal sense; for these are referred entirely to the nose, mouth, and heated or chilled surface of the skin, and not to the outer world. The reference of these three degrees of objective sensations, to their respective external causes, is connected with different mental processes; but, in all cases, an inference is drawn, that they depend on properties of external objects or forces. Thus an agreeable odour is a property of the rose, and a green colour of chlorophyll. At first, however, in the infant, sensations are not associated with ideas, or related, through perception, with external objects; but the mind, by some innate process, soon compares sensations, caused by such objects, with those which arise in the interior, and learns to discriminate them from the latter, and so to distinguish the objective "self," from the outer world. The recognition of the subjective "ego," is a still higher mental act.

Though sensations are, in the normal condition, inseparably linked with consciousness, they may be unattended to, or cease to be regarded by the attentive mind, *i.e.*, by the mind acting in the state called *attention*; the sensations are then so transitory, that they have been named, though, it is here submitted, erroneously, *unconscious sensations*, a concatenation of terms, apparently illogical, and contrary to fact. In the most perfect sensation, the whole attention must be concentrated upon the sensory impression.

The *velocity* of sensory impressions, in their paths from the peripheral organs to the sensorial nervous centres, has been already mentioned (page 279). This velocity is measurable, but so rapid, that, within the limits of the body, the moment of sensation practically coincides with the moment of impression. The *intensity* of a sensation, is proportional to that of its exciting cause, the state of the sensorial apparatus being equal; but we are unable to perceive any measureably corresponding strength, in the sensations produced; as, for example, in degrees of flavour, or shades of brightness. The impressions made upon the senses of touch and sight, however, yield us definite measurements of space and time. The relative *acuteness* of sensation, is determined by the ability to distinguish the feeblest stimuli, or stimuli differing but very slightly in intensity. Weak stimuli require a longer period of action than strong ones.

The apparent *duration* of sensations, varies in the different senses, and is also influenced by the state of the nerves concerned; thus, the duration of impressions *photographed* on the retina, is sufficiently long, to enable a luminous circle to be produced, by whirling a point of light through the air, and doubtless explains the streaming lights seen in artificial fireworks, and the track of light which a meteor, or falling star, leaves behind it; but the duration of light on the retina, is limited, otherwise one set of images would habitually blend with preceding or succeeding ones, as the eye shifted its direction. Again, the duration of auditory impressions is undoubted, but not practically sufficient to interfere with the function of hearing. The impressions of smell, and especially those of taste, are more durable, probably, however, because the odorous and sapid particles, which excite them, are not removed, but continue to act on the sentient extremities of the nerves. The duration of sensory impressions on the skin, depends chiefly, on the length of time, during which the par-

ticular stimulating body has been applied to it, the instantaneous prick of a pin, leaving an evanescent sensation, whilst the longer contact of the same body, is followed by a more lasting effect. Sensations, occurring in debilitated states of the health, or in weakened conditions of the nutrition of the nerves and nervous centres, are more durable than those occurring in the healthy state ; in the latter case, the nutrient effort of the nervous substance more quickly restores it from the peculiar condition of change, produced by its stimulation.

After-sensations, more or less distinct, are noticed in regard to all the senses. They depend on the persistence of the disturbed state of the sensory apparatus, nerve, or sensorial nervous centre, which parts are not immediately restored to a condition of rest or equilibrium. These after-effects endure longer in enfeebled states of the sensory apparatus, or in debilitated states of the nervous substance, as illustrated in the case of ocular *spectra*, which remain longer on the retina, in persons in whom that part of the eye, is enfeebled by age or other causes. Ocular spectra recur, as well as persist.

Certain sensations are accompanied by other or *associated* sensations. These arise, either from simple radiation of the same sensation, as in the extension of a luminous impression on the retina, and the diffusion of a painful sensation through inflamed or excited nerves, as in neuralgia of the face from tooth-ache; or from the excitation of a different sensation, as when a cold, or creeping, sensation is caused along the back, or the teeth are set on edge, by disagreeable jarring sounds, like that produced by drawing a slate pencil vertically upon a slate, or by tearing silk or calico.

The *repetition*, if moderate, of a sensation, has the effect of strengthening the power of the sensory organ, nerve, or centre, or of all three parts. This is illustrated by the exercise of a particular sense, as, *e.g.*, of the eye by sailors, of the ear by the practised musician, of taste and smell by wine- and tea-tasters, and of the sense of touch by watchmakers, silk-weavers, and others. But the too frequent repetition of powerful sensations, exhausts part of, or all, the sensorial apparatus. It is also to be observed, that whilst the repetition of the same sensory impressions, may strengthen the sensory faculty, it at the same time weakens the power of attention to such sensations, especially if these be monotonous, like the ticking of a clock, or the clack of a mill; and thus persons become habituated to sounds, and also to continued

odours, whether agreeable or disagreeable, without attending to, or perceiving, them.

The *alternation* of different sensations, or of sensory impressions of the same kind, but differing in degree, is a most effectual mode of educating the senses.

Remarkable individual peculiarities, quite within the limits of health, are observable in different persons, as regards their respective powers of sensation. Some of these may be due to education, training, or habit; but many are only to be explained, by reference to individual peculiarities of endowment. For example, there are persons unable to distinguish certain tones, especially the various intermediate gradations between two musical notes; there are also persons, as we shall hereafter explain, who are unable to appreciate certain colours, and are hence named *colour-blind*; and instances of defective smell are likewise met with. National peculiarities of sensation, may account for the love of certain colours, and for the special love of music, noticeable in different peoples.

Exaltations of sensation occur in the so-called mesmeric, somnambulistic, or hypnotic states; for in these, the senses of temperature, touch, and hearing, may be acutely manifested.

It is not known whether such peculiarities and exaltations of sensation, are owing to modifications in the recipient surface or organ, in the internuncial nerves, or in the sensorial centres. Probably, in the case of individual or national peculiarities, all these parts are modified; but in the so-called mesmeric exaltation, the change is perhaps limited to the sensorial nervous centres.

Suspensions of sensation may be produced in several ways: thus, the topical application of cold, ether, chloroform, morphia, or other anæsthetic agents to the sensory surface or organ, may suspend sensation locally. Pressure, ligature, disease, or division of the internuncial nerve, may also interrupt or destroy sensation. Effusions of blood, softening, or other morbid changes in the sensorial nervous centre, are equally fatal to the sensory functions. Narcotics, taken internally, or injected under the skin, and chloroform and ether inhaled through the lungs, also suspend sensation, by their general action. There is one natural mode of suspension of the action of the senses, which remains to be mentioned, and that is *sleep*, the influence of which is to be explained by its effects, not on the sensorial surface, or the conducting nerve, but on the sensorial nervous centres or common sensorium. It is said

that, under the influence of sleep, sight, the most acute sense, is the first to be suspended, then taste and smell, next hearing, and lastly, touch.

The memory cannot recall common sensations, nor, except rarely, the sensations proper to the special senses; but it can, the mental perceptions produced as the result of these.

The *variety* of sensations manifested by man, is very great, and the ordinary subdivision of these, into common sensation, and five special senses, viz., sight, hearing, smell, taste, and touch, by no means sufficiently or scientifically expresses the whole range of our bodily sensations. In such a classification, the sense of touch is recognised as distinct and special, though more often regarded as a simple modification of the common sensibility. Again, it neglects the distinctive characters of certain other sensations, by including them under the head of common sensation, especially the sense of temperature, *i.e.*, of heat and cold, the muscular sense or the sense of internal effort and resistance, the sensations of hunger, thirst, nausea, satiety, want of breath, fatigue, and exhaustion; and, lastly, the feelings which accompany certain mental states, such as imaginary sensations, and the peculiar sensations experienced in deep emotions, whether pleasurable or painful. From these so-called modifications of common sensibility, the sensations proper to the muscular system have been removed, and treated of as belonging to a special sense, under the name of the *sixth sense*. The researches of Schiff and Brown Séquard (page 341), have, moreover, led those physiologists to the belief, that special paths of conduction exist in the spinal cord, for the sensations of *touch*, *temperature*, and *pain*; so that perhaps the true tactile sense should be distinguished from common sensation, to which pain may be referred, and the sense of temperature from both.

Special Sensation.

The causes of the *variety* of sensations, whether common or special, are very obscure. Common sensation is the basis of the special sensations, or the fundamental type of sensibility. Touch is plainly a modification of it, and, in this general view, even taste, smell, hearing, and sight, are but special adaptations of a common sensory faculty. The organs of the special senses, even the nose, the ear, and the eye, are formed out of inverted portions of the common surface of the embryo, which,

for the development of those specially constructed and complex organs, undergo peculiar metamorphoses, to adapt each for the reception and *translation* of its proper external stimulus, so that this may excite the energy of the nerve and nervous centres. Besides the special recipient apparatus, however, there are special internuncial nerves, and special sensorial nervous centres. Moreover, it is supposed that these nerves have special endowments to suit them for their respective offices, and that the nerve centres possess distinct physiological properties or modes of reaction under external stimulation.

The special susceptibility of each sensorial centre, whether of that of sight, hearing, smell, or taste, is said to be proved by the fact, that internal changes in these centres, may produce corresponding sensations, independently of the co-operation of either the special nerves or recipient apparatus. In cases of amaurosis, or loss of visual power in the retina or nervous expansion of the eyeball, luminous spectra have been excited by internal causes; and galvanism, applied to a person deprived of one eye, has been known to cause luminous impressions on the blind side. But to these facts, it may be objected, that, in the first case, the recipient organ was still connected with the brain, and might not have been altogether disorganised; and in the second case, that the luminous impressions might have been erroneously referred to the blind side, or have been the result of a recurrent action of the sound eye. A common internal stimulus, such as an excess of blood in the capillaries of the nervous centres, is frequently known to produce flashes of light, noises, or odours, according to the sensorial centre affected; but in such cases, it must be remembered that these parts are still in connection with their respective recipient organs. This is also the case, when so-called ocular spectra are seen, some of which are so definite in shape, detail, and colour, as to resemble external objects, or persons, familiar to the subject of such spectral illusions, and, indeed, so defined, that we cannot conceive of their production amongst the nerve cells of the sensorial centre, but must refer them to the preliminary formation of definite *patterns* of images upon the retinal structure. The same objection may be made to instances of the sensation of light being caused by pressure on the brain, of sparks, of buzzing or other noises, and of creeping sensations in the skin, being produced by narcotic agents, in all which cases, the recipient organs are still connected with the sensorial nervous centres. The results of the

application of a common external stimulus, such as a blow, pressure, or electrical shocks, to the various sensory organs, all of which undoubtedly produce the sensations of light and colour in the eye, loud or ringing noises in the ear, a salt or acid taste in the tongue, and shock or pricking in the skin, are open to the same objection. As to the effects of direct stimulation of the trunks of the gustatory, olfactory, or auditory nerves, by electricity or mechanical means, nothing is known; direct irritation of the optic nerve, is said to produce not pain but a sensation of light; no such experiment, however, has yet been made, after the complete removal of *both* eyeballs, and therefore, even if one eye had been removed, some recurrent effects may have been produced through the retinal elements of the remaining eye.

The existence of a special susceptibility in the internuncial nerves of the different senses, is inferred from similar, but equally defective, evidence to that adduced in regard to the supposed distinct endowments of the sensorial centres. It has even been assumed, that they possess, not only a special irritability as regards certain heterologous stimuli, but special qualities which can generate, under ordinary or homologous stimulation, peculiar sensations in the several sensorial centres; but the proofs adduced are of the same imperfect character; and some disturbance, or altered condition, of the *recipient apparatus* still in connection with the nerves, may have been the cause of the specific reaction of the nerve and its nervous centre. The well-known phenomenon of sensations referred to the lost toes or fingers, after amputation of the limbs, presents an example of localised sensation, dependent on irritation of a nerve-trunk; but such sensations are not special, or such as apparently require a recipient organ to excite them. They resemble rather the sensation of pins and needles in the little finger, produced by a blow upon the ulnar nerve at the elbow, and consist of modifications of pain, rather than of definite tactile impressions, or impressions of temperature, such as can only be produced through the cutaneous organs.

The phenomena of special sensation and its varieties, may perhaps be accounted for, without assuming the existence of absolutely distinct physiological endowments in the internuncial nerves and nervous centres. The conducting and recipient powers of these, may be the same, or fundamentally alike; their structure, at least, presents no recognisable difference sufficient to account for any absolute difference of endowment; any

disturbance in their molecular constitution, produced by a sensory impression, may be supposed to involve the same vito-chemical and vito-physical changes in the substance and condition of the nervous elements, whether characterized by oxidation, heat, or internal motion; these changes may present merely correlated differences in *kind*, or in *degree*, in regard to each sense; the peculiarities, or different degrees, of these changes, may depend on the difference in the external stimuli which, in the case of each special sense, are able to act upon the nervous substance; and lastly, the object of the specialised recipient surface or apparatus in each sensory organ, the *only* part of each organ of sense, in which we can detect most manifest, varied, and singularly adapted structure and contrivance, may be to mediate between the special stimulus and the common fundamental nervous endowment, to translate that stimulus into nervous energy, and so to excite peculiar modes of reaction in a similar nervous substance. When our knowledge concerning the conditions or changes which take place in the nervous substance in common sensation, is complete, we may be able to explain the modifications in those changes or conditions, which are essential to special sensation.

All sensations, though realised through the mental state called consciousness, which is *beyond our means of investigation*, depend ultimately, as objects of physiological study, on certain corporeal states, or changes, in the sensorial nervous centres. These changes, or states, are produced, as we have explained, either by *external* or *internal* stimuli; the external stimuli in question, differ remarkably in their source and nature; and there must obviously be a strict correspondence between the variety of reactions in the nervous substance, and the nature of these stimuli. May not, therefore, the differences presented by the various stimuli to sensation, furnish us with the means of classifying the sensations themselves? Thus the external stimuli produce distinct impressions corresponding to the sensations of sight, hearing, smell, taste, the tactile sense, and the sense of temperature, all of which may be regarded as distinct senses. Sight informs us of the existence of light and colour; the sense of temperature conveys to us the knowledge of the existence of heat; and these two senses would seem to have a certain natural alliance with each other. Again, the senses of smell and taste are also allied. Lastly the sense of hearing, as we shall immediately show, is closely allied to that of touch. All the senses are excitable by the electric energy.

These six special senses may, according to this view, be

arranged in three groups, each containing two related or coupled senses. The first group consists of two *molar*, or *dynamical*, senses, viz., touch and hearing, the senses of matter in *contact*, and of matter in *motion*, or the *tactile* and *acoustic* senses; the former reveals to us the presence of matter itself, by the pressure of substance against substance, whilst the latter conveys to us the effects produced by particles of matter undergoing motions which cause the phenomenon of sound. The second group is *chemical*, and includes *taste* and *smell*, the former acting *dialytically*, the latter perhaps *catalytically*. Both depend on chemical reactions, which take place in the extremities of their respective nerves, and are allied by the common property of recognising those forms of *molecular* motion, which occur in acts of chemical combination or decomposition. Taste, however, requires, as one of its conditions, the dialytic penetration of a chemical substance in solution, through the soft tissues, to the extremities of the gustatory nerves; whilst smell appears to require the concurrence of a catalytic act of chemical combination, between oxygen, or some other agent, and the odorous matter, at the surface of the olfactory membrane, to which, as we shall hereafter describe, certain pointed appendages of the olfactory nerves actually reach. Lastly, in the third group are contained the *thermic* and the *photic* senses, which convey to us the effects of those further kinds of undulatory movements, occurring between the molecules and supposed *intermolecular* ether, or in the intermolecular ether itself (or in the centres and periphery of those spheres of force, of which matter, by some, is supposed to consist), upon which the phenomena of heat and light are believed to depend,—movements and phenomena so far related, that, though heat may be manifested to us without light, and light without heat, yet heat of a certain intensity is always accompanied by luminosity. These two senses we might group together as the *etheric* senses. So regarded, the six senses may be thus arranged:—

Molar or Dynamical senses . .	Tactile—Touch. Acoustic—Hearing.
Molecular or Chemical senses .	Dialytic—Taste. Catalytic—Smell.
Intermolecular or Etheric senses .	Thermic—Temperature. Photic—Sight.

By means of these senses, all our knowledge of the *matter* and *energy* of external nature, is obtained, and all our psychical

faculties are called into action. In the absence of the most important senses, indeed, man sinks intellectually below many animals. These six senses necessarily correspond with those properties and actions, physical, chemical, and material, of the world around us, which are cognisable by us, and the effects of which, communicated to special recipient surfaces, must produce, through special mediating and translating apparatus, corresponding changes in the nervous substance. It is now generally believed, that all the energic phenomena, or manifestations of force in nature, are correlated, or, as it were, capable of transformation into each other: mechanical motion producing heat; heat, chemical action; both in their turn, light, and so on; so that, according to this view, the photic, thermic, chemical, and mechanical stimuli in nature, are all correlated. In the same way, is it not probable that, to receive, react against, and feel, these various forms of correlated stimuli, there may exist in the nervous system, but one common functional excitability, or one common and essential nervous energy, to be excited by these stimuli; and if all active physical effects are to be traced to different modes of motion, in the molecules or intermolecular ether, in external, dead, *non-nervous* matter, may not all nervous action, concerned in sensation, likewise depend upon different molecular and intermolecular modes of reaction, in internal, living, *nervous* matter?

On this, or some similar view, of a *harmony* between the physical phenomena of external nature, and the nervous reactions excited within the sensorium, can we alone believe in, or explain the possibility of our attaining accuracy and fixedness of knowledge concerning external objects and phenomena; for without such internal and external correspondences, no real knowledge would be possible, and, certainly, no community of knowledge, ideas, or thought, between different individuals or generations, could exist.

Concerning the *completeness* of the human senses, in regard to external nature, no certainty can ever be attained; for, if there be agencies in nature, other than those which now produce sensations within us, it is impossible to prove their existence, unless our organisation were so changed, as to enable us to perceive them. It is, however, as unphilosophical to suggest a limit to the number of modes of action of the common force of nature, as it is to assume the existence of such modes as we cannot possibly establish by proof; for we cannot deny the existence of other modes of action of the force of nature,

which may be unperceived, only because they are imperceptible to us. But the mind naturally inclines to a belief in a certain completeness in the series of our senses, and in the harmony established between them and the modes of action of the common energy of external nature. Moreover, there is reason to believe, that the nervous energy manifested in nervous reaction, is itself correlated with that common force.

With regard to the possibility of the possession of *additional* external senses by animals (for no one believes them to possess additional internal senses), it may be stated, that this is a question beyond our means of investigation. However, as a conclusion, based on general considerations, Man being undeniably the most highly organised creature on the earth, it is highly improbable that the nervous systems of any of the animals lower than himself, are endowed with special sensorial powers, enabling them to recognise modes of action of the common force of nature, which pass undetected by him, because they are inoperative upon his sensorial nervous substance. Man probably is endowed with every *kind* of sensation possessed by animals, though each special sense may, in certain animals, be more highly developed. In the warm-blooded Vertebrata, the same senses undoubtedly exist, as in Man, though modified in acuteness in different instances. In the cold-blooded Vertebrata, especially in Amphibia and Fishes, the low temperature of the body would seem incompatible with so high a grade of sensibility as exists in the warm-blooded species, unless, indeed, their nervous substance be differently endowed. The influence of a low temperature is probably more felt in regard to common sensibility, touch, taste, and smell, than in hearing and sight, which, so far as the structure of their recipient organs, the ear and the eye, will permit, may be very acute in these animals. Still lower in the animal series, as in the aquatic Mollusca, the similarity of temperature between the body and the external medium, and the simplification of the sensory apparatus, are doubtless associated with a further diminution of activity in the function of sensation. In the Molluscoida, special sensation is probably almost entirely replaced by common sensibility. In the Annulose animals, those in which the temperature is comparatively high, viz., the Insects, probably enjoy, not only greater special sensibility, particularly as regards sight, but also a more acute common sensibility than the colder aquatic Annulosa, such as the Crustacea and Annelida. In these animals, movements excited by external irritation, by no means imply the acuteness of sensibility which is generally supposed. In the Annuloid animals, and also in the Cœlenterata, special sensibility can only be feebly manifested by those few species which possess simple ocular spots, and the so-called auditory sacs; whilst their common sensibility must be extremely feeble. In the Protozoa, sensibility to light, or the warmth which accompanies it, is noticeable, in the Infusoria; but in regard to any other sensation, there is no distinct evidence of its presence in these the lowest animals.

In conclusion, it may be added, that in no animal, are actions or movements observed, which require, for their explanation, the supposition

of the existence of any additional sense; so that, not only are we unable, from the nature of things, to prove the existence of additional senses in animals, but their behaviour does not justify the inference, that such senses are present in them.

The utility of each sense is very greatly enhanced by the numerous *qualitative* sensations, which we are enabled to experience through it; such, for example, as the almost endless distinctions of light and shadow, colour and hue, force, pitch and timbre of sound, and the numerous varieties of odours and tastes. The qualities of sensation perceived through the same sense, are, indeed, most diverse. The causes of the qualitative differences of colour and of sound, are closely related, being, in both, dependent on definite numerical relations between the numbers of the luminous or sonorous undulations; but, as regards smell and taste, no such relations have yet been established.

Pain.

When any of these external senses, or senses responding to external causes, are unduly excited by their proper stimuli highly intensified, *pain* is the result, as is shown by the effect of gazing at the sun, or at any other extremely vivid light, especially if long continued, and also by the effects of shrill, loud, and grating noises; but the pain, in each of these cases, is *peculiar*. That which is caused by acrid smells, very pungent tastes, the action of irritants on the naked cutis after blisters, the pressure of sharp points or heavy weights, and by bodies in rapid motion, in the organs of smell, taste, and touch, is due to excessive stimulation of the common sensibility. The occurrence of pain, from the over-excitement of the special senses, indicates their relation to this common sensibility. It is said, however, that powerful *mechanical* stimulation of the optic nerve, causes no pain, but intense luminous sensations; this is probably dependent on the still existing connection of the nerve with at least one eyeball. But it is the common sensibility which is ordinarily excited in the feeling of pain. Such pain is not merely an intensified normal sensation; for very hot bodies cause a painful, and not an exalted thermal sensation. The common sensibility is also actively concerned in those various sensations which inform us of the conditions of the nervous centres, produced, not by external stimuli, giving us a knowledge of external objects and forces, but by internal states of the organism; for these so-called *internal sensations*, some of

which are pleasurable and some painful, seem to be distinct modifications of common sensation.

Internal or Corporeal Sensations.

These *internal sensations*, though dependent, as just stated, on conditions of the nervous system, are, like the external sensations, usually referred to special seats, that is, to certain tissues or organs of the body, and hence may be called *corporeal.* Some are referred to the organs of *animal* life, and others to the organs of *vegetative* life.

Of the former, the muscular sensations are the most important; the sensation of resistance within the joints, is also very evident. The internal sensations proper to the states of the nervous system, or the *nervous* internal sensations, are those of pain generally, especially of neuralgic pains, sensations of vertigo, torpor, drowsiness, mental fatigue, nervous exhaustion or shock, and irresistible tendency to sleep.

The *muscular* sensations are those of uncomfortableness, restlessness, muscular languor, faintness, lassitude, heaviness, fatigue, weariness, as shown in the heavy falling eyelids and bodily exhaustion which precede sleep, intermittent spasm and cramp, and the feelings of general health, buoyancy, bodily energy, and capacity for corporeal work. It is also by a similar class of sensations, which, less vague in their seat, are known under the collective name of the *muscular sense*, that we become conscious of the degree of effort made, or of the resistance met with and overcome, in regulating the amount of force employed in all the muscular movements of the body, such as lifting or moving weights, resisting external forces, balancing the body in walking, moving the arms in the performance of prehensile and manipulative acts, and exercising the organs of voice and speech. When this sense is lost in certain muscles, their actions can no longer be regulated, or even commanded, except through the agency of the sight (page 363). On board a ship in a rolling sea, the muscular sense is called into unusual activity to neutralise the effect of the motions of the vessel, which disturb the equilibrium of the body ; on returning to land, the compensatory movements rendered necessary at sea, continue for a time.

To this sense, moreover, we owe our feeling of the stability of position of the body, in sitting or in standing ; when it is wanting, vertigo or giddiness ensues, caused by a loss of

the sense of equilibrium, and accompanied by staggering efforts at recovery of position, or by falling. Vertigo may be produced by rapid rotatory movements of the body, whether active or passive; also by the long maintenance of the horizontal posture, by various diseases, by injuries of the head, and by many medicinal agents. Though manifested by, and referred to, muscular actions, its real cause is some disturbance in the nervous centres, which govern and co-ordinate these movements.

Our notions of space and distance, are also derived, or deduced as inferences, from the exercise of the muscular sense, which enables us to determine the precise position of the body, when at rest, or in motion through space. The relative positions of external bodies, whether these be at rest or in motion, are also determined by reference to the fixed or moveable state of our own bodies. If we are at rest, moving objects appear to us to move, and stationary ones to be fixed. But if, being at rest, we imagine ourselves, through a disturbance of the muscular sense, to be in motion, or if we perform irregular and erroneously estimated movements, then external objects seem to move accordingly; on the contrary, the movements of outward objects may, after a time, seem to depend on motion in our own bodies. In the former case, we refer a bodily condition of movement to the outer world; in the latter, movements in the outer world are referred to a supposed bodily condition. In this latter case, giddiness may be produced, even after the eyes are closed. This state, which is known as *secondary vertigo*, may be produced by steadfastly looking at quickly moving objects, by after impressions caused by moving objects, by looking down from great heights, and by rapid, unusual movements of the body. Rotatory movements will produce vertigo, even though the eyes be closed.

Lastly, to the muscular sense, combined with certain feelings of pressure and strain about the joints, seated probably in the ends of the bones which support the cartilages, and in the ligaments which tie the bones together, we are indebted for our notions of resistance and of weight; these, however, are not the results of a simple sensation, but of inferences drawn from the perception of the effects of gravity and force. The muscular sense appears to be keenly exalted in somnambulists, as well as the power of muscular combination and control. It has been suggested, that the special sensorial centre of this muscular sense is in the cerebellum (page 366). This, however,

seems improbable, for when it is lost in any particular muscle or muscles, the common sensibility disappears with it; hence, it has been regarded as only a modification of this common sensibility.

The internal sensations dependent on states of the organs of *vegetative* life, are exceedingly varied, in accordance with the number and variety of those organs themselves. Many of them must be produced by impressions made on the ultimate ramifications of the sympathetic nerve, or of branches of the cerebro-spinal nerves which are associated with these in their distribution. They are chiefly referable, either to the digestive organs, the organs of circulation, or the respiratory organs.

The internal sensations connected with the *digestive system*, are thirst, hunger, satiety, and nausea. *Thirst* is principally a local sensation, being chiefly referred to part of the tongue and palate; but it is evidently dependent upon a general state, for it may be distinguished from mere dryness of the mouth and fauces. This latter condition, which is produced by sleeping with the mouth open, is quickly relieved by shutting it, or, at most, by merely moistening the mouth with water, and immediately emptying that cavity. True thirst is not so relieved, but only by copious drinking, or by continued immersion of the body in water, even though this be salt. The general condition on which thirst immediately depends, appears to be a deficiency of water in the blood; and as the blood is the source of all the secretions, these are everywhere diminished, and those of the fauces and mouth are necessarily deficient. An additional cause of dryness in the throat especially, is, that its surface is momentarily exposed to evaporation in the respiratory act, so that thirst is consequently localised in the fauces. The sense of dryness of those parts, is communicated to the sensorium, by impressions conveyed along the fifth, the glossopharyngeal, and the pneumogastric nerves, the two latter of which are probably more sensitive than other nerves, to the condition of dryness. Not only the want of water in the blood, produces this feeling, but the excess of saline matter will likewise cause it, as is noticed after taking much common salt with the food, drinking salt water, or even taking draughts of neutral vegetable salts, such as seidlitz powders. It is also produced by hot condiments, and by strong alcoholic beverages. It is particularly and distressingly noticeable in cases of hemorrhage after gun-shot wounds or other extensive injuries, and in all cases of fever. The in-

tense thirst experienced by shipwrecked sailors, and by criminals subjected to the torture of thirst, is accompanied by burning pains and sufferings, more difficult to bear even than those induced by prolonged starvation, and ending in delirium and mania. Thirst is more immediately and successfully quenched by water than by any other fluid. It is water which the system absorbs from the blood, in thirst, the tissues, as well as the secretions, requiring it; and the introduction or imbibition of this fluid, is the natural remedy for this sensation.

The sensations of *appetite* and *hunger*, the former of which is pleasant, and the latter painful, are by some regarded as chiefly muscular sensations. They are referred to the stomach, in the same way as thirst is referred to the mouth; but, like the latter sensation, they would seem to depend on a general condition of the system, and perhaps essentially on some state of the blood. The muscles of mastication are said to participate in the sensation of appetite; and a flow of saliva is excited by it. It may be supposed that the nerves of the stomach convey the sensations proper to that state of the system induced by fasting, more readily than the nerves of any other part of the body. Several theories have been suggested, to explain the gnawing feeling of hunger, which is even more decidedly felt in the stomach, than appetite. Some physiologists, offering a mechanical explanation, have thought that it is owing to the rubbing together of the sides of the empty stomach; but this explanation is opposed to the facts, that the stomach may be empty, without hunger being felt, and that, in the fasting condition, when hunger is experienced, the walls of the stomach are quiescent. As a chemical theory of the cause of hunger, it has been suggested, that it depends on irritation excited by unused gastric juice; but no gastric juice is secreted during fasting. A physiological explanation consists in supposing that the feeling of hunger is owing to a turgescence of the blood vessels of the mucous membrane of the stomach; but this membrane is pale when the stomach is empty; indeed, the secretion of gastric juice takes place rapidly, and the membrane then suddenly becomes red. That the sensation of hunger depends partly on some condition of the stomach itself, is shown by the fact, that it may be allayed by the introduction into that cavity of almost, or perfectly, indigestible substances, such as sawdust, or clay; even when the stomach is filled with digestible substances, the feeling of hunger is relieved, before any material quantity of digested food

can have been absorbed. Hunger is not, however, so speedily relieved as thirst. On the other hand, that it depends mainly on a peculiar condition of the system, is shown by the experiments of injecting nutrient substances, in the form of enemata, or into the blood itself, either of which is followed by a cessation of the feeling of hunger. The nerves distributed to the stomach, which are concerned in this sensation, must either be derived from the pneumogastric, or from the sympathetic nerve; but the latter, it must be remembered, contains fibres derived from the cerebro-spinal system. It has been shown that the sense of hunger, as manifested by the desire of animals for food, is not permanently destroyed, but merely diminished, after division of the pneumogastric nerves (Reid and Bernard); but whether the persistence of hunger, is owing to the subsequent reunion of those nerves, or to the action of the still uninjured sympathetic branches, is not known. The sensation of *satiety* is said to persist in animals, as evidenced by their conduct, even after division of the pneumogastric nerves; but the experiments on this point are not satisfactory. The final cause of the sensation of hunger, not only in animals, but in man, is to impel them to seek for the food absolutely necessary to sustain life; and indirectly, hunger may be said to stimulate men, in an uncivilised state, to the chase, or to mutual conflict, and, in civilised society, to the exercise of their intellect and bodies, in industrial and other occupations.

The progress from fasting to *starvation*, is at first accompanied by an exaggeration of the sensation of hunger to a ravenous craving after food; but after a time, if unsatisfied, this sensation passes off, a condition of indifference to food supervenes, and no further sensation of appetite is experienced, extreme prostration and diminution of sensibility setting in, and ending in delirium and death.

Another sensation, chiefly referred to the stomach, is that of *nausea*, which, however, is often accompanied by distressing sensations about the pharynx and palate, and by general sensations of depression, sinking at the precordia or pit of the stomach, and a lowering of the heart's action. It is said to be a muscular sensation (Weber), though formerly it was regarded as a modified gustatory sensation. It may be produced in many ways, as, by irritation of the stomach, indigestion, improper quality or quantity of the food or drink, or by emetic medicines introduced either into the stomach, or the lower part of the alimentary canal, or injected beneath the skin, so that

they can be absorbed into the blood, or even by the injection of such substances directly into the blood vessels. Nausea may also be induced through the nervous system, as a reflex phenomenon, by tickling the fauces, or by the inhalation of chloroform (through its action on the brain), by odours or tastes, by the motion of vessels at sea, by severe pain, by concussion or diseases of the brain, by conditions of the blood in the early stages of fever, by the sympathetic effect of various diseases, by general shock from severe injuries, especially from blows over the great solar plexus, and even by mental causes. It is certain, therefore, that this sensation of nausea, or sickness, though referred to the stomach, must depend, sometimes, at least, upon general conditions of the system. The movement excited by the condition of nausea or sickness, named *vomiting*, will be mentioned after the description of the movements of the stomach, in the Section on Digestion.

The internal sensations associated with the *circulating system*, are fewer than those connected with the digestive organs, at least in a state of health, in which not even the powerful and incessant action of the heart is perceived by the mind. Were it otherwise, the amount of attention given by the mind to such internal sensations, would occupy it, so as to interfere with its perception of external phenomena. In weak conditions of health, in sudden excitement, and in certain diseases, however, the sensation of *palpitation of the heart* is not uncommon. The sensation of *fluttering* at the pit of the stomach is usually not cardiac, but either diaphragmatic or gastric. *Heartburn* is also erroneously named; for it is a gastric sensation, dependent on the accumulation of acid, or other acrid fluid in the stomach. In morbid conditions, actual pain is felt in the heart; and, in mental states, a sense of weariness is referred to that region. Morbid sensations of heat or chilliness along the veins, or in the blood, as such feelings are termed, are probably owing to conditions, not of the vessels or blood, but of the nerves of common sensation, especially of those of the skin.

Of the internal sensations connected with the *respiratory organs*, by far the most powerful is that known under the name of the feeling of *want of breath*. It is this which creates an irresistible desire to inhale air, and an uncontrollable involuntary effort to inspire. Its final cause is undoubtedly to maintain life, which is so immediately dependent upon the continuance of the respiratory function. It is difficult to de-

termine the precise seat to which this sensation is referred; but it is chiefly located in the larynx and neighbouring parts of the throat, and also in the anterior part of the chest and precordia, opposite the level of the diaphragm; it is probably, in great part, a muscular sensation. Its cause is, however, general, and perhaps depends on the presence of an undue quantity of carbonic acid in the blood, which, reaching the nervous centres concerned in receiving impressions from the respiratory organs, and in governing the respiratory movements, at once excites the sensation of distress, and the involuntary impulse to inspire, which is best calculated to relieve it. The sensation of want of breath is named *apnœa*. Difficulty of breathing is named *dyspnœa*, an embarrassing sensation also referred to the larynx, throat, and chest. These conditions may be produced by diminution in the number and depth of the respirations, by breathing a vitiated atmosphere, by obstacles to the introduction of fresh air into the lungs, as in asthma and œdema of the larynx, by diminution of the respiratory surface, as the result of disease, and by defective action of the blood as a conveyer of oxygen.

With regard to the muscular sensations of the contractile organs employed in the functions of digestion, circulation, and respiration, it is remarkable that the *respiratory muscles*, although they are identical in structure with the rest of the voluntary muscles, and are themselves subject to the will, and, though they are constantly in action during the whole of life, yet do not habitually, and in healthy conditions, convey the sense of fatigue to the mind. As regards the *heart*, no direct sense of fatigue in its muscular walls, is experienced. So also, the movements of the stomach and intestines are usually unperceived. In inflammation of any of the parts just considered, as of the intercostal muscles, the diaphragm, the heart, and the alimentary canal, acute pain, spasm, or cramp, is not uncommon.

The organs of vegetative life are, it would seem, in health, possessed of little or no sensibility; but when irritated, inflamed, or organically diseased, they become more or less acutely sensitive; just as the common sensibility, and even the special sensibility, manifested by the organs of animal life, may, when unduly exalted, give rise to pain. Pain is a necessary consequence of sensibility; and almost every tissue or organ, when inflamed, gives rise to a peculiar pain. Painful sensations, however, are frequently not precise. They are

often erroneously localised, especially in cases of diseases of parts not ordinarily sensitive. The radiation of severe pains is a familiar fact; and the irradiated pains are often more severe than those in the seat of the primary irritation; for the latter may even cease, from exhaustion of the nerves. Pain also renders nerves incapable of re-action under normal stimuli.

Pain is as old in the world, as the existence of a sensory nervous apparatus; the gift of sensibility is necessarily accompanied by a liability to pain. The tension of the nervous energy connected with feeling, is, as it were, adapted to certain ranges of strength in the stimuli which excite sensation; and such an adaptation necessarily implies, that when the limits of agreeable stimulation are exceeded, pain is the result. According to this view, pain is a necessary evil, under the existing relations between the nervous system and external agencies. But, happily, pain itself cannot be conceived by the imagination, nor recalled by any effort of the memory, and is, for the most part, transitory. Considered teleologically, pain has a beneficent action, surpassing that of pleasure, which may, through uncontrolled appetite and desire, lead to the undue use, that is to the abuse, of the various functions. Pain, moreover, is conservative, suggesting the necessity for moderation and caution, in the exercise of the functions, both of animal and vegetative life. Pain also is preservative, creating a feeling of alarm and a sense of danger, by exciting, through nervous sympathy, or through the blood, other organs or distant parts of the system. Thus pain in a single part, excites general febrile disturbance, and so the whole system may be said to take warning. Pain also forms a chief consideration in the symptomatology and diagnosis of disease, which may thus be detected, and combated in time to save life. The importance of pain in morbid processes, is recognised in the term *dis-ease*, the obvious etymology of which is, as we ordinarily pronounce the word, forgotten. Pain is, moreover, the cause of wide sympathies between individual persons; fellow-suffering excites human charity and beneficence. It is to be noted, that, in the ordinary act of dying, the sensitive portion of our frame, or the sensorium, dies before the merely motor apparatus, with its excito-motor or non-sensitive nervous centres; and thus, the senses are subdued, and, as it were, annihilated, sometimes long before the last breath is drawn. Finally, it may be not unworthy of note, that whilst limited suffering is the inevitable lot of sensitive animals, the relief of

that suffering by narcotic and anæsthetic agents, such as henbane, opium, ether, or chloroform, ordinarily necessitates the co-operation of substances derived directly, or indirectly, from the vegetable kingdom.

THE SENSE OF TOUCH.

The Organ of Touch.

THE skin is the principal part of the body concerned in the sense of touch, but the tongue and lips also possess this sense. The nails and hairs are appendages of the skin, and often minister to the sense of touch. The skin is further provided with sebaceous and sudoriferous glands. It constitutes a protecting covering to the whole body, and is known as the *common integument.*

The skin consists of an external or superficial layer, destitute of blood vessels and nerves, named the *cuticle*, fig. 66, 1, 2; and of an internal or deeper layer, abundantly supplied with nerves, and highly vascular, known as the *cutis vera* or *true skin*, 3. These two layers, though separable, are closely adherent.

The skin is thicker on the back than on the front of the body, thicker on the outer than on the inner surface of the limbs, thicker still in the palms of the hands—but thickest of all in the soles of the feet. It is very thin on the eyelids, in the tube of the ear, and on the red borders of the lips, where it becomes continuous with the mucous membrane of the mouth. The surface of the skin is marked with fine intersecting lines or furrows, which divide it into minute angular spaces; these are large opposite the foldings of the joints. On the soles and palms, and especially on the toes and fingers, the skin is elevated into little ridges, usually parallel to one another, which sweep over the surface in curved lines, fig. 65; they correspond with rows of the vascular eminences belonging to the true skin, named the papillæ.

The *cuticle*, also called the *epidermis* (επι, upon, and δερμα, the skin), is made up of superimposed layers of nucleated epidermoid cells. (See p. 72, fig. 43.) The superficial cells, figs. 66, 67, 1, are flattened, dry, and transparent, and firmly held together, assuming at the surface, the form of thin, coherent, horny scales; the cells in the deeper layers, 2, 2, resting on the cutis, are soft, roundish, or compressed, and

easily separated from each other; this deeper layer is known as the *rete mucosum of Malpighi*, or, sometimes, as the *Malpighian layer*, or the *mucous layer*. The colour of the skin in the dark races, is due to the presence of pigment, chiefly found in the form of coloured granules, usually situated in certain of the epidermoid cells. These granules are fewer near the surface of the cuticle, where the flattened scales are

Fig. 65.

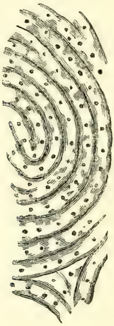


Fig. 65. Portion of the skin from the end of the thumb, slightly magnified, showing the curved ridges and intermediate furrows. Upon the ridges, are seen the orifices of the ducts of the sweat glands.

paler. The colour of the skin is, therefore, chiefly seated in the rete mucosum of the cuticle; the true skin, in the dark races of Men, has the same colour as that of the European.

It is the non-vascular cuticle which, owing to the exudation of a fluid between it and the vascular cutis, forms the blebs or bullæ seen in certain skin diseases, and after burns, scalds, or the application of blisters. On separating the cuticle from the cutis, after death, when some decomposition has taken place, the under surface of the former is found to be accurately moulded to the upper surface of the cutis, closely following all the flexures, markings, and ridges of the skin, which are really formed in the cutis; it further presents numerous small pits or depressions, which receive the conical projections of the cutaneous papillæ. A prolongation of the cuticle lines the sides of the hair follicles, and the glands of the skin.

In the palms and soles, where the entire skin is thickest,

the cuticle measures about $\frac{1}{12}$th of an inch; in other parts, where the skin is very thin, it is not more than $\frac{1}{240}$th of an inch in thickness. In the palms and soles, it grows thicker, from the effects of hard work and pressure. The greater thickness of the whole skin, in some situations, as in the hands and feet, cannot, however, be solely attributed to the effects of external influences, for the skin of these parts is thickest, even

Fig. 66.

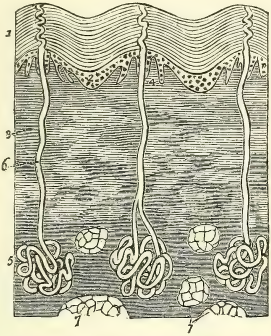


Fig. 66. Vertical section of a portion of the skin of the finger, made across three of the curved ridges, shown in fig. 65, magnified about 20 diameters; 1, section of the dry part of the epidermis. 2, Section of the soft, mucous, or Malpighian rete mucosum, the chief seat of the colouring matter in the dark races. 3, Section of the cutis or derma, gradually becoming more areolar, until it joins the subcutaneous areolar adipose tissue. 4, Elevations of the upper compact portion of the cutis, named the papillæ, placed in rows across the ridges just mentioned. 5, Coiled tubuli of the sudoriferous, or sweat glands, lying near or in the areolar subcutaneous tissue. 6, Long duct of one of these glands, forming a waved line through the cutis, 3, but passing spirally, like a corkscrew, through the cuticle, 1, and then opening on the surface of a ridge. 7, Small masses of the subcutaneous fat. (Kölliker.)

in the new-born infant. During life, the cuticle is constantly undergoing loss, by the process known as desquamation, which consists of a throwing off of the superficial epidermoid scales. But these are constantly being renewed by fresh epidermoid cells, originating on the surface of the true skin, and gradually undergoing transformation, from the spherical to the flattened shape, as they approach the surface of the cuticle.

The *cutis*, or *true skin*, also called the *corium* and *derma*,

figs. 66, 67, 3, covered everywhere by the cuticle, is a dense, moist, tough, and flexible fibro-areolar membrane, of a pinkish-white colour. It is adherent to the subjacent parts generally, becoming blended with the subcutaneous areolar and fatty tissue, the fasciæ, and even with the cutaneous muscles.

The cutis is made up of interlacing bundles of white areolar tissue, mixed with yellow elastic fibres. Immediately beneath the rete mucosum, its structure is almost homogeneous, presenting a compact, scarcely fibrillated appearance. Somewhat deeper, bundles of fine fibres, with small areolæ, appear. In the deepest layers, the fibres are large and coarse; the dense areolar network is here loose, and, opening out, incloses the hair follicles with their sebaceous glands, and small masses of fat. In most situations, scattered contractile fibre-cells, or plain muscular fibres, are found, mixed up with the fibrous and elastic tissues; they are always present where hairs exist, to which parts they are often attached; on the palms and soles, where these are absent, no muscular fibres are ever seen. The cutis, in some parts of the body, as in the palms and soles, is closely adherent to the fascia beneath it; in the face, it gives attachment, by its under surface, to many of the fibres of the muscles of the eyebrows, and mouth. The skin is very loosely attached over the angles of the joints, where, moreover, the so-called *subcutaneous bursæ* are found; these are closed sacs, situated between the integument and the prominences of the bones, by means of which the movements of the parts are facilitated. The thickness of the cutis varies in different parts of the body; it is thickest in the sole, and thinnest in the eyelids, being, in the former situation, about a line and a half thick, and in the latter, less than a quarter of a line; as a rule, it is thicker in the male than in the female. The thickness of the entire skin is determined by the cutis, except in the palms and soles, where the cuticle is disproportionately thick.

The surface of the cutis, as seen when it is denuded, is covered, in many places, with little conical-shaped projections, called *papillæ*, fig. 66, 4. These are prolongations of the upper compact tissue of the cutis, into the rete mucosum of the cuticle, from the depressions in which, already mentioned, they can be drawn out, in macerated specimens, after death. The papillæ are best seen on the palms of the hand, where they are largest and most numerous; they are usually arranged in double rows upon the cutaneous ridges (figs. 65, 66), and are

generally divided, so as to form compound papillæ, 67, *a*. In the palm, the number of *simple* papillæ on a Paris square line, ranges from 150 to 200; upwards of 80 *compound* papillæ have been counted on the same space. (E. Weber.) On the free border of the lips, they are also very numerous, but they do not present any regular arrangement. The cutaneous papillæ on the fingers and palm, measure from $\frac{1}{100}$th to $\frac{1}{200}$th of an

Fig. 67.

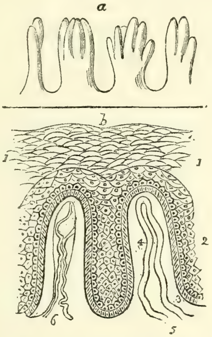


Fig. 67. *a*, a larger view of the cutaneous papillæ, showing the secondary papillæ into which they are often divided. Magnified about 60 diameters. *b*, still larger diagrammatic view of two simple cutaneous papillæ, with their epidermic covering. 1, dry scaly part of epidermis. 2, soft part, or rete mucosum, consisting of compressed cells. 3, cutis, or true skin. 4, papilla. 5, vascular capillary loop in one papilla. 6, tactile corpuscle, with two nerve fibres winding up, and becoming lost upon it. (Kölliker.)

inch in length; in the soles, they are nearly as large, but in other situations, where there is less tactile sensibility, they are few in number, short, small, and scattered, measuring from $\frac{1}{500}$th to $\frac{1}{1500}$th of an inch in length; on some parts of the body, the papillæ become indistinct, or are even altogether absent.

The cutis is abundantly supplied with blood vessels, lymphatics, and nerves. Its general surface is covered with a close capillary network, from which, fine looped vessels project, and enter the papillæ, fig. 67, 5. The lymphatics also form a close network on the surface. The nerves pass upwards from the subcutaneous cellular tissue, and form, as they

approach the surface, minute plexuses, from which nerve fibres are given off. Some of these fibres are lost in the compact tissue of the cutis; others end, perhaps, in loops; whilst, lastly, many of them pass into certain of the papillæ only, for it is said that some of these do not receive nerve fibres. In the papillæ, the fibres end in loops, or, as in the fingers, the sole of the foot, and, according to Kölliker, on the red margin of the lip and the point of the tongue, they appear to terminate on, or in, small oval condensed bodies, called *tactile corpuscles* or *axile bodies*, fig. 67, 6 (Wagner), situated in the centre of the papillæ; or they become lost in the central part of those papillæ which are unprovided with distinct tactile corpuscles. In any case, it has been supposed that the nerve fibre turns back to rejoin some nerve cell in the nervous centres. (Beale.) The tactile corpuscle fills up the greater portion of the papilla, and, according to some, is surrounded by the ends of the nerves; by Gerlach, it is also said to be perforated by them. According to Wagner, these bodies have altogether a special structure; but, by Kölliker, they are said to consist of condensed homogeneous connective tissue, covered by imperfectly developed elastic fibres, resembling the interlacing bundles of areolar tissue and elastic fibres of the true skin. Huxley considers the axile bodies to be formed by the continuation of the neurilemma or sheath of the nerve, which is much developed in this situation. In the conjunctiva, lips, and other parts, the axile body sometimes presents a knob-like form, and consists of a fine nucleated sheath, containing a granular plasma, within which, the axis-cylinder of the nerve ends in a simple blunt point. (Krause.) Their number varies in different parts; on the palmar surface of the distal phalanx of the index finger, there are about 108 on a square line, on the second phalanx 40, on the first 15; on the palmar surface of the metacarpal bone of the little finger and on the middle of the sole of the foot 8, and on the tip of the great toe, 14.

The cutaneous papillæ are vascular organs, serving to increase the nutrient and formative surface for the generation of the constantly wasting epidermis; whilst those which contain nerves, are the proper organs of touch, their number, size, and complex development, being in exact proportion to the perfection of this sense in different parts of the skin. Two kinds of papillæ have been described by Wagner, viz., one containing capillary loops only, and the other being merely provided with nerve fibres and axile bodies; but, according to Kölliker, the

vascular papillæ of the lip contain nerves, and the papillæ of the palm of the hand, which possess axile bodies, frequently contain capillary loops.

In certain situations in the subcutaneous tissue, as in the hands and feet, some of the cutaneous nerve fibres pass into curious little oval bodies, varying from $\frac{1}{15}$th to $\frac{1}{10}$th of an inch in length, named the *Pacinian corpuscles*. These consist of numerous concentric membranous laminæ, composed of spirally arranged fibres, and having between them, spaces filled with fluid. In the centre, is an elongated chamber, into which the axial part of the nerve fibre penetrates, and which also contains a semi-fluid substance. The nerve fibre enters these bodies at a sort of pedicle, together sometimes with a capillary loop; and then, losing its medullary sheath, becomes reduced to its axis-cylinder, and penetrating to the internal chamber, ends in a little bifid or trifid knob, perhaps turning back again. Similar bodies are likewise found on the sympathetic plexuses of the abdomen, in man. In many animals, these corpuscles are found in large numbers in the feet; they are very abundant in the skin, feet, bill, and tongue of birds. They are especially well seen on the mesenteric nerves of the cat.

The *nails* are modified parts of the cuticle, with which they are continuous along the hinder part of their edges, by their upper surface near the root, and by their under surface near the tip; hence, when loosened by decomposition, they slip off from the true skin, in intimate connection with the glove-like cuticle. They consist of a deep soft layer, fig. 68, 2, composed of roundish, somewhat compressed, epidermoid cells, and of a hard superficial stratum, 1, made up of flattened, horny, and intimately adherent cells. The under concave surface of the nails, is accurately moulded on to the cutis or true skin, to which it is firmly adherent during life. The part of the cutis beneath the nail, is called the *matrix*, or *bed*, 5; posteriorly, it is doubled on itself, forming a semilunar *groove*, fig. 68, *b*, or recess, into which the hinder edge or so-called *root* of the nail is closely set. The matrix is highly vascular; it is covered with numerous vascular papillæ, fig. 68, *a*, 5, running lengthwise under the nail; but opposite the crescentic white spot seen near the root of the nail, called the *lunula*, the papillæ are smaller, less vascular, and irregularly scattered.

The nails, like all epidermoid tissues, are constantly being

reproduced, growing in length by continual additions of new cells to their posterior margins, and in thickness by like additions to their under surface. When a nail is torn out, or thrown off, in consequence of disease, a new and perfect nail is formed, provided the matrix is uninjured.

Fig. 68.

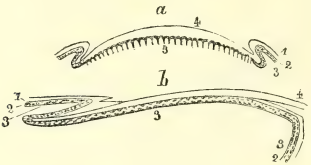


Fig. 68. *a*, transverse section of the nail, and its matrix. *b*, longitudinal section of the same: both figures are diagrammatic. 1, the outer cuticular layer. 2, the rete Malpighianum, or mucous layer, of the cuticle. 3, the cutis. 4, the nail substance. 5, the ridges of the cutis, of which the matrix or bed of the nail consists. (Kölliker.)

The *hairs*, like the nails, are non-vascular and insensible outgrowths of the cuticle, springing from a minute sunken point of the surface of the true skin, which has there no other cuticular covering. They are found on all parts of the body, excepting the palms of the hands, the soles of the feet, the backs of the last phalanges of the fingers and toes, and the surface of the upper eyelids; they present great varieties in length, thickness, and colour, in the male and female, at different ages, and in the various races of mankind. With the exception of the eye-lashes, which are set perpendicularly to the surface, they are usually inserted obliquely into the skin. The soft swollen end of the hair, which is embedded in the skin, is called its *root* or *bulb*, fig. 69, *a*, 5; the part which projects above the surface, is called the stem or *shaft*, and the terminal extremity, the *point*. The shaft is usually cylindrical in shape, but is often somewhat flattened, or even grooved. It consists of an outer part, called the *cortex*, fig. 69, *a*, *b*, *c*, composed of a single layer of adherent and imbricated scales, the edges of which, directed towards the point, form fine wavy transverse lines; beneath the cortex, is the so-called *fibrous* part of the hair, which constitutes its bulk, and consists of fusiform cells clustered into flattened fibres,

which run longitudinally, and are intermixed with pigment granules; lastly, the very deepest cells, occupying the centre of the shaft, and constituting the *pith* or *medulla*, are not elongated into fibres, but are somewhat polyhedral, and loosely connected

Fig. 69.

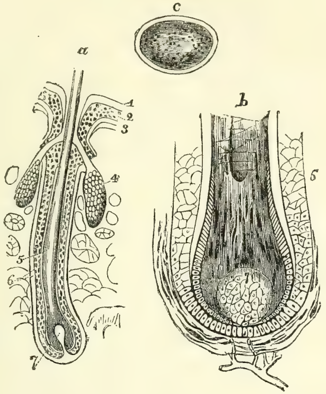


Fig. 69. Diagrams of the structure of the hair, hair follicle or sac, and sebaceous glands (Kölliker). *a*, root of a hair, in its follicle. 1, outer, dry layer of cuticle. 2, Malpighian or mucous layer, both dipping into the hair sac. 3, cutis, or true skin. 4, sebaceous glands, opening into hair sac. 5, root of hair. 6, walls of hair sac. 7, papilla, on which the hair grows. *b*, larger view of lower end of root of hair, and bottom of hair sac. 6, the hair sac, showing the outer and inner root sheath, the latter adhering to the hair. 7, the vascular papilla on which the hair grows. The hair itself shows its fibrous structure, its dark medulla, and the transverse lines of its scaly covering. *c*, transverse section of a hair, showing its outer covering, its fibrous part, and the central softer medulla or pith. (After Kölliker.)

together, containing chiefly pigment or fat granules. The pith is only found in certain hairs, and does not extend so far as the point.

The minute depression from which a hair emerges, is called the *hair follicle*, or hair sac, *a*, *b*, 6. This, which varies from one to three lines in length, is buried in the true skin, or, as in the case of the larger hairs, reaches even into the subcutaneous fat: it receives, in nearly all cases, the ducts of two sebaceous glands, *a*, 4. The sides of the hair follicles, are firm, and consist of two layers, an outer soft, fibrous, and

vascular, and an inner non-vascular homogeneous layer, both being prolongations from the cutis; each follicle is lined by extensions of the horny and soft layers of the cuticle, 1, 2, forming the part called the *root-sheath*, the inner stratum of which adheres closely to the hair. At the bottom of the follicle, is a more or less elevated portion of the cutis, often forming a distinct *papilla*, 7, which is destitute of cuticle, being covered, instead, by the attached extremity of the hair which, indeed, is formed on the papilla. The root of the hair is composed of soft, pale, and somewhat compressed, nucleated cells; it is intimately adherent to the root-sheath or cuticular lining of the follicle; when a hair is plucked out, it comes away with this cuticular lining, which clings closely round its root; the vascular papilla at the bottom of the follicle, however, remains, and a new hair is generated upon it. If the papilla be destroyed by injury or disease, no new hair is formed. The papillæ resemble those on the surface of the true skin, being highly vascular; all, except the papillæ of the finest hairs of the body, probably receive nervous fibrils; for pain is produced when a hair is pulled at, or plucked out. The papillæ situated at the roots of the large whiskers, or *vibrissœ* of the cat, seal, and other animals, which are used as feelers, are supplied with very large nerves. The hairs themselves are destitute of nerves.

It is on the papillæ that the hairs are formed by the production and metamorphosis of a succession of nucleated cells, as in the case of the nails and epidermis. These cells undergo alterations for some distance along the stem of the hair, which so becomes narrower than the root or bulb. The softer central portion, whether deserving the name of the pith or not, though of course non-vascular, is probably permeable to nutrient fluids, which nourish the hair. It is supposed that the sudden whitening of the hair from grief, fear, or intense mental excitement, is due to certain changes in the pith, produced through the blood.

Many of the unstriped muscular fibres, which, as before stated, are found in the substance of the true skin, pass obliquely down from the surface of the cutis, to the under side of the slanting hair follicles. It is the contraction of these fibres, which erects the hairs, by causing them to assume a vertical direction, and which, by drawing the follicles to the surface, and pulling in a little point of the skin, produces that roughness of the integument, generally called *horripilation*,

goose's skin, or *cutis anserina.* The standing on end of the hair of the head, as the result of extreme fright, may be partly due to the contraction of such fibres, but it must also be dependent on the action of the occipito-frontalis muscle.

The *sebaceous* or *fat-forming* glands, fig. 69, *a*, 4, from *sebum*, fat, are situated in the cutis, and exist in great numbers, associated with the hairs, there being usually two for each hair follicle. Those of the larger hair follicles average about $\frac{1}{50}$th of an inch in width. They are proper appendages of the hair follicles, and are not found in the palms and soles, where no hairs exist. Each gland is a flask-shaped body, composed of from five to twenty little sacs, clustered around, and leading into, a common duct, which almost always opens into a hair follicle, each follicle receiving one or more ducts; sometimes, however, the ducts of the glands open upon the cutaneous surface. These glands are lined throughout by a fine epithelium, and their unctuous secretion first anoints the hair-bulb, and then oozes out upon the stem and the neighbouring surface of the cuticle, which it prevents from getting dry and cracked. On the nose and face, the sebaceous glands are of considerable size. The Meibomian glands in the eyelids, are large sebaceous glands.

The *sudoriferous* glands or sweat glands, fig. 66, 5, will be described in the Section on Excretion.

Touch.

The modification of the sensory power, by which the shape, size, solidity, and other mechanical properties or qualities of objects, are distinguished, constitutes the sense of *touch*, or *tact*, or the *tactile sense.* The *sense of temperature* is also usually referred to this sense; and so likewise are the feelings of pain or its opposite. So far as is yet known, the peripheral sensory organs, and the nerve fibres concerned in all these forms of sensation, are the same. But, as already mentioned (p. 341), different paths in the spinal cord, are supposed to be pursued by tactile, thermal, and painful impressions; and instances are recorded, in which the sense of touch was lost, whilst that of temperature remained. As to the exact sensorial centres, excited in each case, nothing is positively determined.

The simplest impression conveyed to the mind by the tactile sense, is, as its name implies, that of *contact* with some

external object, or the *touching of matter.* By the aid of touch, combined with *pressure*, or movement, or with both, we arrive, however, at more important results, viz., at compound impressions. For example, from touch and pressure, we obtain the feeling of external *resistance*; and, according to the degree of this, we acquire a knowledge of the solidity, viscosity, fluidity, or aeriform conditions of matter, and thus gain our notions of hardness, softness, elasticity, impenetrability, and so forth. By touch, combined with movement, we successively arrive at the notions of measure and size, distance and space. By the same means, we examine and appreciate the *forms* of bodies; and by the combined operation of touch, pressure, and movement, we learn the *characters* of *surfaces*, such as roughness, smoothness, or polish. Finally, by touch, co-operating with the muscular sense, or the feeling of *internal resistance*, we are able to appreciate weight. Touch, though the simplest and least special, is the most general, and, at the same time, the most direct, positive, and certain of the senses. It is the logical as well as the physiological parent of the other senses, which are, in the last analysis, modifications of touch. It is the sense the least liable to be deceived.

The sensations of contact and resistance, and also, it may be added, those of temperature, and of pain or its opposite, are always referred to the parts of the body acted on by the external object; in all cases, but especially in the first three, a certain perception of the regions touched, resisted, or heated, that is, of the *locality* or *seat of the sensory impressions*, is superadded; although, as we know, the actual seat of all sensations, is in the part of the great nervous centres, named the sensorium. It is on the more perfect possession of this perception of the locality of impressions of contact, that the specialised form of sensation, which constitutes tact, or the tactile sense, to a large extent, depends.

All parts of the skin, and the adjoining mucous membranes, are endowed with the sense of contact or touch; but, in man, it is the hand, which, by common usage and cultivation, is the special organ of the higher tactile sense. It is most admirably fitted for its office, by reason of the number, size, arrangement, structure, and abundant nervous supply, of its papillæ. The whole mechanism of the upper limb is, indeed, wonderfully adapted for the due fulfilment, not only of the prehensile, but also of the tactile functions of its digital extremities. The numerous articulations of the fingers, the

length of their phalanges, the size and strength of the thumb, the power of bringing it into exact opposition with the ends of the fingers, so as to form, with them, as it were, a pair of pincers, enable the hand to span objects in all directions, and to examine their relative consistence, size, and character of surface. The bones and nails serve as firm points of support for the skin, and aid materially in the exercise of the tactile sense, and in its secondary or derived uses.

Those cutaneous papillæ which contain nerves, are the proper organs of tactile sensibility, their number, size, arrangement, complexity of structure, and nervous supply, being, as exemplified in the hands and feet, in exact proportion to the perfection of this sense in different parts of the skin. The points of these papillæ (see fig. 67, *b*) are situated nearer to the surface of the skin, than the general surface of the cutis from which they project; and the cuticle upon them, receives the pressure of external objects, and transmits it to the papillæ and their nerves. The tactile corpuscles and the Pacinian bodies are not *essential* to the exercise of touch; but they exist only in those situations, in which this sense is most delicate or acute. The tactile corpuscles, far more numerous, and situated so much more superficially than the Pacinian bodies, the former lying in the papillæ of the cutis, and the latter being entirely subcutaneous, may act mechanically, by supporting the expansions of the ends of the tactile nerves, so as to prevent their yielding to objects of touch. Thus, although not essential to sensation, they may serve to intensify the tactile sensibility of a part. The use of the Pacinian corpuscles is quite unknown. Their analogy to the electrical organs of certain fishes, has not escaped attention.

The delicacy of touch has been estimated numerically, by measuring the power possessed by different parts of the surface, of distinguishing the double impression produced by the simultaneous application of the two points of a pair of compasses. (Weber.) It presents marked differences in different situations; it is greatest at the tip of the tongue, and the end of the third finger. It was found, by Weber, that if the eyes be closed, and the points of a pair of compasses, protected by cork, be applied to either of the parts just named, the double impression is distinctly perceived when the points are approximated to within half a line of each other; for the perception of the double impression on the palmar surface of the last phalanges of the thumb and fingers, the points of the

compasses must be separated, one line; on the red surface of the lip, two lines; on the middle of the dorsum of the tongue, four lines; on the lower part of the forehead, ten lines; on the sternum, twenty lines; lastly, on the middle of the fore-arm, on the middle of the thigh, and over the middle of the cervical and dorsal vertebræ, the two impressions are not perceived, unless the points of the compasses are at a distance of thirty lines from each other; these last are the portions of the cutaneous surface in which the sense of touch is least perfect. The sensibility of the trunk is said to be greater in the middle line in front and behind, than at the sides.

It will thus be seen, that the delicacy of touch in the most sensitive parts, is about sixty times greater than it is in the least sensitive parts; it presents, however, considerable differences in different individuals. It has been shown, by Valentin, that some persons can distinguish the double impression at one-third of the distance at which it can be felt by others. The smallest distance at which the two points of the compasses can be distinguished, is called the limit of confusion. (Graves.) The two impressions of the points of the compasses, are more plainly perceived, when these are placed in a direction transversely to the trunk or limbs, than when they are applied in a longitudinal direction; but it is said, that at the point of the tongue and the tips of the fingers, the two impressions are more easily felt when the points are applied in the longitudinal direction. The two points can, moreover, be distinguished at much shorter distances, when they are applied consecutively, than when they are made to touch simultaneously. (Czermak.)

Accompanying the double sensation of the two points, is a distinct feeling of interspace between them; and if the points of the compasses be drawn, with a certain rapidity, over a tract of skin, they always appear, to the mind of the person experimented upon, to be further apart, as they pass over regions possessing a relatively greater sensibility, or sense of space. When the compasses are drawn in the opposite direction, the points seem to approach each other. Not only, therefore, are the points felt distinct at shorter distances in the more sensitive parts, but they seem to be more distant; this distance also seems greater when they are applied consecutively and not simultaneously. At a certain short distance, the feeling of interspace disappears, but gives way to the sensation of an elongated body, and finally to that of a single

point. If one point be cold and the other warm, they are felt, even at short distances, as double, although their relative position cannot be recognised.

The thinness of the epidermis, under certain circumstances, favours the acuteness of the tactile sense, as is shown in the comparison between the outer and inner aspects of a limb; but the delicacy of touch in the fingers is proverbial, although their epidermis is very thick. Touching or irritating the naked cutis causes pain, not a tactile sensation.

It is most probable that the delicacy of touch, and the power of discriminating distance, are proportional to the number of nerve fibres supplying the skin, and indirectly, therefore, to the number of papillæ. If two impressions be made on a part sparingly supplied with separate nerve fibres, such impressions may travel to the sensorium, only along one fibre, in which case, only a single impression will be perceived. It has been assumed, that each cutaneous nerve fibre ends in a pencil of delicate filaments, for the supply of a definite circular or oval area of the skin, the diameter of which has been estimated at probably about $\frac{1}{400}$ of an inch; but the filaments of adjacent nerve fibres, are supposed to pass into contiguous areas, so that the exact spot of the body, which is the seat of a single impression, is recognised by the aid of compound impressions. On this view, a theory is offered as to the sense of locality possessed by the skin, viz., that the smaller these areas—*i.e.* the more numerous and closer the nerve fibres—the greater the acuteness of this sense of space. (Fick.)

The curious observation has been made, that a part endowed with a finer sense of space, *feels* a part less endowed in that respect, and not the latter, the former; when, *e.g.*, the finger touches the forehead, it is the finger which feels the forehead, and not the forehead the finger. For this experiment, the two parts of the skin must be of the same temperature; for when two regions of the skin of different temperatures, are brought in contact, a double sensation is produced.

A useful instrument named an *æsthesiometer*, consisting of a graduated bar, having a fixed and moveable point attached to it, has been devised for testing the relative sensibility of different parts of the skin, in cases of more or less complete *anæsthesia*, or *paralysis of sensation*.

There is no necessary relation between the delicacy of the tactile sense in a part, and its common sensibility, for in some regions of the skin, where the perception of tactile impressions

is very perfect, common sensibility is much less marked than it is in other regions, where the sense of touch is much less acute. In the soles of the feet, the arm-pits, and the flanks, parts endowed with but little tactile sensibility, the sensation of tickling can be most easily excited; but on the ends of the fingers, where the delicacy of touch is highly developed, it is difficult to produce tickling.

Experiments have been made to determine the relative sensibility of the skin, by placing weights on different portions of the body, and ascertaining what is the minimum weight capable of exciting a tactile impression. It was found, by Aubert and Kammler, that a body, weighing two milligrammes, and covering one square millimetre, could be distinguished upon the face; whereas, on the pulp of the fingers, a body occupying the same area, must weigh from ten to fifteen milligrammes, in order to produce a distinct sensation of pressure. But the sensibility of the face was considerably diminished, when the minute hairs covering its surface were shaved off. The left half of the body is said to be, as a rule, better able to appreciate weights by their pressure on the skin, than the right half. The sensation of pressure in different parts of the skin, does not exhibit such marked differences as that of the sense of space. Increase of pressure is more easily perceived than a diminution of the same. (Panum and Dohrn.) It is easier to distinguish small differences with light weights, than with heavy ones. (Weber and Fechner.) Slight differences in two weights, can be more easily discriminated, when these are placed on the same part of the skin a little time after each other, than when they are simultaneously applied close together.

Pressure only does not, however, convey to the mind a correct idea of weight, for bodies appear heavier when their pressure is made to act on a small surface of the skin than when it is extended over a larger area. The sensation of the muscular effort required to resist the pressure, is a much more important guide in judging of the weights of bodies. Thus Weber has shown, that if the eyes are closed, and two weights, one of which is somewhat heavier than the other, be placed, one on either hand, we are unable to appreciate any difference between them, so long as the hands are supported on cushions; but the moment the hands are raised, the muscular effort thus made, immediately informs us of a difference between the weights. The muscular sense is here brought into play.

As already mentioned, the mere contact of an object with the organ of touch, only conveys the notion of resistance; but a notion of the *extent* of *surface* of an object, is arrived at by alterations in the relative position of the organ of touch and the object touched, and, in this, we are also assisted by the muscular sense, which gives us a knowledge of the positions of the arm and hand.

The knowledge of the *dimensions*, *shape* of *surface*, and *distance* of objects, is obtained in two ways. Either we judge by the relative distance and position of two or more, or even of many, points of the sensory surface of the part of the body employed in the act of feeling, with the motion or situation of which, we are accurately informed by the cutaneous sense of locality; or we touch in succession, several points of the objects to be examined, with the same sensory surface of the body, and then, by the extent and direction of the movements necessarily performed by us in these acts, judge of the size and form of the object in question. In the former case, our perceptions become more accurate when the acts of contact with the foreign body are successive, than when such contacts take place simultaneously; moreover, the acts of contact, when successive, must neither be too quick nor too slow, or we lose the power of judgment from them. In these applied uses of the sense of touch and the muscular sense, for the formation of compound ideas and notions, we are, in practice, greatly and habitually assisted by the sense of sight.

Long continued impressions on the nerves of touch leave after, or secondary impressions, which sometimes persist for a long period; as, when a person in the habit of wearing a ring, believes that he still feels it, after he has left it off. These *after impressions* are dependent on some altered condition of the skin. The general after effects of continued and successive tactile impressions are remarkable. Thus, if the hand is brought into contact with a rapidly revolving disc, the edge of which is provided with uniform fine teeth, alternate and distinct tactile sensations of contact and non-contact, are produced. With a certain velocity, these remain distinct, but at very high velocities, the two sensations become less so, and resemble in character, those known as rough or woolly. Still more rapid revolutions of the disc, at length produce uniform sensations, which are comparable with that of smoothness or even with that of complete polish. (Valentin.)

Continued uniform pressure upon any portion of the skin,

ceases, after a time, to produce any impression; but when the pressure is no longer uniform, *i.e.*, if it be lessened or augmented, its presence is immediately noticed. If the pressure, after having been uniformly kept up for any length of time, be removed, an after sensation, as usual, remains.

The mind, as already mentioned, generally refers the sensations of touch to the part of the skin stimulated, but, under certain circumstances, they are referred altogether to the exterior. Thus, when an object is brought into contact with parts destitute of nerves, like the hairs or nails, the effect is communicated, through them, to the sensory portion of the skin from which they grow, and gives rise to sensations which are distinctly referred to the insensible hair or nail. In the same manner, the sensations of touch are sometimes referred to the extremity of a foreign body in contact with the skin ; thus if a stick be held by one end, and its other end be brought into contact with any object, we perceive a two-fold impression one, where the stick is held, and another, which is referred to the end of the stick touching the foreign body.

The sense of touch can be excited, as it is said, subjectively or by *internal* causes; thus, the sensations of formication creeping, or tingling, may arise independently of external influences : such tactile sensations are of frequent occurrence.

The sense of touch is capable of being *educated*, as is well seen amongst the blind, whose tactile discrimination is so acute and delicate, that they are able to read sentences in raised letters, to distinguish the inscriptions and impressions on coins and frequently even to recognise shades of colour, which escape the notice of the eye, by means of differences of texture and surface. It has been found, that the sense of space or locality, as determined by experiments with the compasses, or with the æthesiometer, is well developed in the case of blind persons, not only in the hands, but even in all the other parts of the body. In persons born without arms, the sense of touch in the toes sometimes becomes, by dint of education, so highly developed, that these can be used in the same manner as the fingers. The influence of habit, in improving the delicacy of the tactile sense, is illustrated by the mode in which factory girls can detect and join the finest fibres of silk and cotton, in the spinning machines. The Bengalee female silk throwsters are said to be able to distinguish, by the touch, as many as twenty different degrees of fineness in the fibres of the cocoons. It has even been alleged, in regard to the in

fluence of education on the tactile sense, that an improvement, in this respect, in any part, on one side of the body, is accompanied by a corresponding improvement in the same part of the body on the opposite side.

Hallucinations connected with the sense of touch are not uncommon. A familiar example is that afforded by crossing two fingers of the same hand, and rolling between them a small rounded body, such as a pea, when the sensation of a double body is experienced. If the point of one's tongue be so touched, two tongues are felt. A stick pressed simultaneously against the upper and lower lip, appears to be straight, but if one lip be moved sideways, or if both be moved in opposite directions, the stick seems to be broken; if this experiment is performed before a looking-glass, the illusion is at once dispelled. (Czermak.) If a body, such as a ball, be touched with sticks of different lengths, whilst the eyes are turned in another direction, it will be found that, when the sticks are carried round the body, this appears smaller the greater the length of the stick, the angle which is then described being much smaller. These are errors of judgment, based on sensations with which we are not familiar. In transplantation of a portion of skin from one part to another, as in the formation of a new nose by a flap of skin turned down from the forehead, but still left connected with that part, by a narrow bridge of integument, the sensations are, for a time, referred to their old seat; so that, when the new-formed nose is touched, the sensation is felt as if it were in the forehead. This is the case, however, only so long as the nerves in the connecting bridge of skin are undivided, and it is uncertain whether the mistake can be corrected by the aid of vision. If the connecting nerves are cut through, all sensibility is temporarily lost in the new nose, until, after a time, new nerves enter it through the cicatrix.

The Sense of Temperature.

By means of a peculiar modification of sensation, we appreciate those intermolecular motions, which cause changes of *temperature in the skin*, and thus arrive at notions of the temperature of external objects, whether these affect us by actual contact and conduction, or, without contact, by radiation.

Impressions of heat or cold, or *thermal sensations*, can only be communicated to the extremities of the nerves of the skin or adjacent parts of the mucous surfaces; that is, through

some *recipient sensory surface*; for it is impossible to excite such impressions, by acting directly on the very nerves which ultimately transmit them. For example: on the raw surfaces left after destruction of the whole thickness of the skin in burns, the sense of temperature is lost, heat or cold, applied to such surfaces, merely producing pain. The skin over the ulnar nerve, behind the elbow, does not exhibit greater sensibility to moderate differences in temperature, than other parts of the body; but when the degree of heat or cold passes certain limits, pain is the only sensation experienced; a mixture of ice and water applied over this nerve, causes intense pain in a few seconds. In the same manner, the contact of frozen quicksilvèr, or solid carbonic acid, with the skin, causes a painful sensation similar to that produced by touching red-hot iron.

Thermal sensations are excited by bodies, the temperature of which ranges between 50° and 117° Fahr.; above or below those points, objects no longer excite the feeling of heat or cold, but cause a sensation of pain. Water at a temperature of about 130° no longer feels warm, but imparts a slight burning sensation; in the same manner, the feeling of cold is no longer experienced a few degrees above the freezing point, painful sensations being then produced.

Sensations of heat or cold are not absolute, but are relative to the temperature of the part of the body acted upon. Hence, objects appear warm or cold, in proportion to the temperature of the body at the time of contact, imparting the sensation of warmth or heat, when their temperature is higher than that of the body, and the feeling of cold, when it is lower. The temperature of the hand is a few degrees lower than that of parts nearer to the centre of the body; hence, when placed in the arm-pit, it feels cold, whereas the axilla appears warm to the hand. So long as the temperature of the skin remains constant, thermal sensations in it are very slight, or altogether absent, for the various temperatures of the skin of the cheeks, hands, feet, and other parts, do not usually excite in us sensations of temperature. When the amount of heat given off, or taken up, in a stated time, is proportionally great, the sensation of heat or cold is persistent; for sensations of temperature are experienced, not only during the immediate changes of temperature in the skin, but also during the passage of a certain quantity of heat through it.

The experiments of Weber show that the sense of tempera-

ture is much modified, according to the extent of surface of the body exposed to the impression, the greater the extent of surface exposed, the more intense being the impression produced. Thus, if the whole of one hand be placed in water heated to a temperature of 102°, and one finger alone of the other hand, in water heated to 104°, the temperature of the former will appear much higher than that of the latter. Slight differences of temperature can be recognised by the whole hand, which are not perceptible if a single finger be employed.

The sensibility of the skin to differences of temperature, varies in different individuals and in different parts of the body; this is undoubtedly in part dependent on differences in the degree of thickness of the epidermis. The tip of the tongue, the face, the fingers, and the soles of the feet, are the parts in which thermal sensations are most easily and acutely felt. It is said that, with the tip of the tongue, variations of temperature of even $\frac{1}{2}$° can be distinguished. The sensibility of the left hand to temperature is more delicate than that of the right. Weber found, that if both hands are immersed in separate vessels of hot water, the left hand always appears the warmer, even though the temperature of the water in which it is immersed, be 1° or 2° colder than that in which the right hand is placed.

The sensations excited are more intense, when the alterations in the temperature of the skin are rapidly effected. When a portion of the skin is cooled by immersion in water at a low temperature, say 55°, and is then immersed in water at 68°, a feeling of heat is experienced for a few seconds, whilst the temperature of the skin rises, but a permanent sensation of cold then follows, because the temperature of the water is still much lower than that of the skin. Cold bodies, which are good conductors of heat, such as the metals, appear to us colder than other bodies of the same temperature, which, like wood, are bad conductors of heat, because the quantity of heat absorbed in a given time from the skin is greater. The sensation of burning is communicated to the hand by air at a temperature of 302°, by wood at 212°, and by mercury at 144°. Those bodies which have a high specific heat, and which absorb and render latent large quantities of heat, also act more powerfully on the thermal sense.

It is supposed, that the giving up of heat by the skin, which takes place when a cold body is brought into contact with it, causes a contraction of the cutis and its papillæ, and that the

taking up of heat, which ensues when a warm body is brought into contact with the skin, leads to the dilatation of those parts, and that, in this manner, the nerves are acted upon, and the sensory impressions of cold and heat are produced. This refers to cases, in which the heat is conducted into or from the body, by some material substance, either solid, fluid, vaporous, or gaseous, actually in contact with it. But the nerves which receive and convey thermal impressions to the sensorium, are also affected, as we know, by radiant heat coming to, or issuing from, the body. In this case also, the heat is still conducted to or from the extremities of the nerves, by material substance, viz. that of the skin itself, the temperature of which is elevated, or depressed, by the reception, or loss, of radiant heat. Accordingly, the nerves are probably not excited by the entering or departing radiant heat itself, but by the heat conducted to, or from, them by the warmed or cooled skin.

In parts of the body, in which there is incomplete paralysis of sensation, the sense of temperature remains, or is the last to disappear; so that paralysed parts, which are no longer sensible to pressure or pricking, still remain sensible to the influence of heat and cold. This may be explained, either by supposing the existence of special sets of nerves for the conveyance of thermal impressions, or the occurrence of peculiar changes in the path of the proper tactile sensations in the cord, or in the corresponding sensorial centres in the cerebrum.

The mucous membrane of the alimentary canal generally, is incapable of receiving impressions of thermal differences, though these are felt in the mouth, pharynx, and, for a short distance, down the œsophagus. In the stomach or intestines, cold or hot water produces corresponding sensations of cold or heat, only when the temperature of the adjacent skin of the abdomen is itself lowered, or elevated, by the conduction of heat to or from it, from or to the alimentary canal in which the hot or cold water is contained.

Subjective sensations of heat or cold are very common in cases of disease. That of cold, in the stage of ague, and that of heat, in febrile conditions of the system, bear no relation to the actual temperature of the body. The former is supposed to be due to a contracted state of the muscular coats of the blood vessels, and of the non-striated muscular fibres of the skin, which conditions diminish the supply of blood to the part. The heat in fever, is attributed to the increased activity of the circulation, and of the metamorphosis of the tissues.

Sensations of heat may be confounded with tactile impressions, even in those parts of the body in which sensibility is most highly developed. (Fick and Wunderli.)

It is supposed, that the reason why the only sensation experienced, on immersing the hand or foot in mercury, or a warm fluid, is that of a ring around the limb at the surface of the liquid, is due to the fact, that the portion of the limb immersed, being subjected to uniform pressure, its papillæ are not excited, but only those corresponding to the line at which the different pressures exerted by the air and by the fluid, meet.

The Organs and Sense of Touch in Animals.

Amongst the *Vertebrata*, in Mammalia, as in Man, the whole surface of the body possesses not only common sensibility and a general sense of touch, except in those species in which, as in the Armadillo, the integument presents a thick, horny, or bony covering, but the proper tactile sense is principally exercised by parts provided with nervous papillæ. In most Quadrumana, the tips of the toes and *fingers*, where the sense of touch is most acute, are abundantly supplied with papillæ, and the under surface of the prehensile tail of certain monkeys, which likewise has many papillæ, is also a tactile organ. In many Rodentia, the pulps of the digits are highly sensitive. In the Bat, the sense of touch is extraordinarily developed in the *wings*, by which means, it can avoid objects during its flight, even when the eyes are extirpated. (Spallanzani.) The *whiskers* or *vibrissæ* of the Carnivorous tribes, especially in the cat and seal, and also those of many rodents, as in the rabbit and hare, are endowed with very acute tactile sensibility. The bulbs of these vibrissæ are very large, and each receives a nerve, often of considerable size, derived from offsets of the infra-orbital branch of the fifth cranial nerves; when these whiskers are cut off, the sense of touch in the animal, is seriously impaired.

But in the greater number of Mammalia, the *lips* and the end of the *nose* are the special seats of touch, many, as the ant-eaters, mole, hog, tapir, and elephant, being provided with a moveable snout. In the rhinoceros, there is a soft hook-like expansion of the upper lip, which is constantly kept moistened, to ensure its sensibility. The snout of the tapir is more developed than that of the pig, and the tactile sensibility of the tip of the elephant's trunk, is second only to that of the human hand. The skin of the zoophagous Cetacea is very remarkable for the thickness and density of its structure. The true skin consists of a thick dense whitish opaque fibro-cellular layer, provided with innumerable elongated papillæ, which enter into corresponding depressions on the under surface of the thick black epidermoid layer. These papillæ are half-an-inch or more in length, and are said to be supplied with nerves as well as vessels. It has been supposed, by many familiar with the habits of the whale, that the sense of touch is very acute in these animals, especially for undulations transmitted through the water; and that, in this way, the whales can communicate with each other when

alarmed. In Mammalia, the soft moveable papillated *tongue* is undoubtedly used as a tactile organ.

The general nature of the covering of the skin in *Birds*, offers a great obstacle to the reception of external impressions. The toes have but few nerves, and are usually so covered on their under surface, as scarcely to be regarded as tactile organs ; whilst the extremities of the anterior limbs or wings, are utterly unsuited to such a function. The sense of touch in birds, must, therefore, be chiefly resident in the bill ; this, though usually hard, is soft in the snipes and woodcocks, which search for their food in marshy ground, and also in the flat-billed water birds ; in these, it is abundantly supplied with nerves. In a few birds, the tongue is papillated, and probably serves as a tactile organ.

Amongst *Reptiles*, the sense of touch is but feebly developed. The tongue of the Ophidia, and of many Saurian reptiles, is considered to be an organ of touch.

The naked, soft skin of the *Amphibia*, is abundantly supplied with nerves, and is, therefore, well adapted for the reception of sensory impressions ; but the proper tactile sense resides principally in the skin over the tip of the jaws, and also in that of the limbs.

In *Fishes*, the soft lips, the parts about the mouth, and, in some species, the pectoral fins, are the seats of the sense of touch. In a few, as in the gurnards, there are digitate appendages connected with the pectoral fins, which seem to be endowed with tactile sensibility.

In the Mollusca, touch must be supposed to reside in the general soft integument ; but it seems to be more acute near the orifice of the mouth in the Cephalopods and Gasteropods, and at the margins of the mantle of the Lamellibranchiata. Many are provided with retractile feelers or other appendages, specially connected with the head, such as the horns of the snails, and the arms of the cuttle-fish. The tentacles of the Polyzoa and other Molluscoida, are highly sensitive.

In the Annulosa, highly developed tactile organs exist, as, *e.g.*, the jointed antennæ possessed by insects, which present the most remarkable varieties of form, and, in certain cases, are so important, that when they are removed, these creatures are no longer able to follow their usual habits. In the ants, the antennæ seem to be employed as means of communication between different individuals. In certain cases, the palpi and feet may assist the tactile sense in insects. In the Crustacea generally, the antennæ, of which there are frequently two pairs, are undoubtedly sensitive tactile organs, and the prehensile jaws and feet may also conduct tactile impressions. The Myriapods also have articulated feelers. The Arachnida, which have no antennæ, possess palpi ; but the exquisite sense of touch, which the spinning Spiders must possess, resides probably in the feet, especially in the terminal joints. The ovipositors of many insects, probably possess a tactile sense, to inform these animals as to the fitness of the place of deposit for the eggs. In the Worms, there are frequently found appendages, in the form of folds, threads, or setæ, often arranged in rows on the body, frequently in whirls, or they are confined to the head, a region which, even if destitute of appendages, is highly sensitive to the touch. Amongst the Annuloida, the revolving-wheels of the Rotifera generally, and the proboscis of some species, are probably tactile. The marine parasitic species have a soft sensitive integument. The succulent feet of the Echinodermata are also remarkably irritable, if not sensitive.

In the Cœlenterata, the ectoderm, especially over the oral tentacles, possesses keen excitability; but they do not apparently exhibit much discriminating sense, seizing all objects alike. The Protozoa, destitute of a nervous system, exhibit no tactile organs.

In all cases, the integument of the Vertebrata consists of a vascular cutis, or true skin, covered by a non-vascular epidermic layer, and is moreover, often provided with various appendages. Some of these, such as the hairs, spines, nails, claws, hoofs, and even the horns of the Mammalia, are epidermic structures, formed on papillæ or matrices, developments of the cutis or true skin. In a few instances, the dense dermal plates of the rhinoceros, and the bony plates of the armadillo, are formed apparently, beneath the epidermis, on the surface of the true skin, and are partly vascular tissues; they belong to the so-called *dermal* skeleton or *exo-skeleton*, as distinguished from the *endo-skeleton* or skeleton proper.

In Birds, feathers take the place of hairs, being, like these, epidermic formations, developed upon papillæ at the bottom of follicles, and having, like hairs, a root sheath, one layer of which, however, closes the young follicle, and for a time invests the growing feather, but ultimately is broken through, and falls away. The quill of the feather consists of fibres and flat scales, and, for a time, contains a portion of the vascular papilla or pulp; the shaft, barbs, and barbules, consist of a pith composed of polyhedral cells, and of an outer firmer layer, composed of flattened epidermoid scales.

Amongst Reptiles, the thick coriaceous integument of certain saurians, the osseous plates of the crocodiles, the scales of serpents, and the horny coverings of the Chelonia, are also epidermic formations, beneath which, in the crocodiles, bony matter is formed, constituting a dermal skeleton; but in the Chelonia, the bony case beneath the horn, named the plastron and carapace, is formed by the expansion and coalescence of parts of the internal skeleton.

The soft integument of the Amphibia, in many cases, almost resembles a mucous membrane.

In Fishes, the integuments are either soft, as in the eels, in which they are still provided with minute scales, or they are covered with the characteristic larger dermoid scales, the pattern and formation of which, have led to important distinctions in this large class; sometimes they present numerous dermal plates or spines. The scales consist of an outer laminated, and sometimes canaliculated, shining layer, composed of the so called *enamel* or *ganoin*, and of a deep layer, which may be horny, fibrous, or even bony; in the latter case, it sometimes contains Haversian canals. The bony scales, and also the bony plates and spines, of certain fishes, are partly epidermoid structures, but are probably also in part, formed by conversions of the outer layer of the dermis; they have great analogy to teeth, especially to the teeth of fishes themselves. The spines of the fins of fishes, are also dermal structures, belonging to the exo-skeleton, and not to the internal skeleton.

The cutaneous glands, both sebaceous and sudoriferous, are found in all Mammalia, except when the integument is covered with horny or bony plates. In Birds, the chelonian and ophidian Reptiles, and Fishes, the cutaneous glands appear to be wanting; in the saurian Reptiles, they are small and few; in the Amphibia, cutaneous glands of a peculiar structure are very abundant. The so-called glands, or mucous canals

and follicles, along the lateral line of fishes, corresponding with the Savian bodies of the torpedo, are believed by Leydig, to be really sensory organs, contained in depressions, or canals, formed in the integument. They are lined with epithelium, and often contain a knob-like projection, abundantly supplied with nerves derived from branches of the fifth pair, or of the pneumogastric nerve. Some of the so-called cutaneous glands of the Amphibia, just described, may be of a similar nature. They must be acted on by irritating solids, fluids, or gases, present in the water, just as irritants act on the soft tongues of the mammalia; they may thus give warning of danger.

In the soft skinned Mollusca, Molluscoida, Annelida, and Cœlenterata, the outer layer of the integument does not consist of flattened epidermoid scales, but of soft spheroidal cells with thick walls, often covered with a structureless membrane. The laminated shells of these animals, when they exist, are formed by the calcification of a nacreous excretion from the surface of the true skin beneath the thin epidermis, which is best seen at the growing margin of the shell. The calcareous substance is almost entirely carbonate of lime. The shell of the tunicated Molluscoida is formed, not by excretion, but by the conversion of their cellulose integument, into structures resembling shell, cartilage, bone, or even dentine. (Huxley.)

The calcareous shell of the larger Crustacea, the horny coverings of others, the chitinous integument of the Myriapoda and many of the Insecta, and the coriaceous skin of the Arachnida, are sub-epidermic structures, formed by various thickenings, fibrillations, calcifications, and other changes of the epidermis, and of certain layers excreted beneath it. The spines, hairs, and microscopic scales of Insects, are epidermic.

Cutaneous glands are represented in the non-vertebrate animals, by peculiar cæcal follicles and tubes found in a few Annelida, Insecta, and Mollusca. The chromatophores of certain Mollusca, and the thread cells of the Cœlenterata, are not glands.

The nervous substance of the warm and cold-blooded animals must be adapted to suit very different ranges of temperature.

THE SENSE OF TASTE.

The Organ of Taste.

The *tongue* is the organ chiefly concerned in the sense of *taste*; other parts of the mouth, however, especially the under surface of the *soft palate*, and the anterior pillars of the *fauces*, are also endowed with this sense.

The tongue is a muscular, vascular, and nervous organ, made up of two symmetrical halves, joined in the middle line. It is composed chiefly of muscular fibres, some of which are proper to it; but the greater number proceed from other parts, to its base and under surface. The apex, sides, upper surface, and forepart of the under surface, are free; by its under and back part, it is attached to the lower jaw, the

hyoid bone, and the styloid process of the temporal bone; it is also connected with the pharynx and soft palate, by means of the anterior and posterior pillars of the fauces; and lastly, it is connected to the epiglottis and neighbouring parts, by reflections of the mucous membrane of the mouth. A fold of this membrane, seen beneath the tip of the tongue, forms the *frænum linguæ.* The apex of the tongue is thinner and narrower than the rest of the organ; the dorsum, or upper surface, is convex, and presents along the middle line a furrow called the *raphé*, which ends behind in a depression, the *foramen cœcum.*

The dorsum, edges, and tip of the tongue, have a peculiar rough appearance, differing altogether from the smooth character of the mucous membrane covering its under surface and the rest of the interior of the mouth, and depending on the presence of little eminences, named *papillæ.* These somewhat resemble the papillæ of the skin, and are of three kinds, named the *filiform*, *fungiform*, and *circumvallate* papillæ.

Fig. 70.

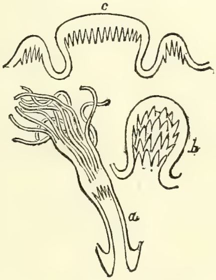


Fig. 70. Diagrammatic view of the papillæ of the tongue (Kölliker). *a*, filiform papilla, showing its vascular core or centre, with its secondary papillæ, buried in the thick epithelium, which ends in a brush, of hair-like character. *b*, fungiform papilla, with its numerous secondary papillæ, and thin epithelial covering. *c*, circumvallate papilla, its secondary papillæ, and their epithelial covering.

The *filiform* papillæ, so called from their thread-like shape, are by far the most numerous; they are found closely set over the anterior three-fourths of the tongue, being especially well marked along the central part; at the sides and tip, they become shorter, and are arranged in oblique, or almost trans-

verse parallel ridges, which gradually disappear as they run to the under surface of the organ; they are of a whitish colour, being covered by a dense and thick epithelium, which is divided, at the apices, into a brush of very fine filaments (fig. 70, *a*). They are set, for the most part, with a slight inclination backwards. Their use is mechanical, and they aid in the tactile sense, but not directly in the sense of taste.

The *fungiform* papillæ, so called because they are expanded at their free extremities, are scattered irregularly over the dorsum of the tongue, chiefly over its anterior half; they are not so numerous as the filiform papillæ, but are of larger size; they are of a deep red colour, and are covered by a thin soft epithelium (fig. 70, *b*). The *circumvallate* papillæ, also red, and covered by a delicate epithelium, are still fewer in number, varying from eight to fifteen, but they are the largest in size. Each is placed at the bottom of a cup-shaped depression (fig. 70, *c*), so as to be encircled by a little furrow or trench, which being itself surrounded by an elevated rim, or diminutive vallum, has given rise to the name circumvallate, applied to these papillæ. They occupy the back part of the tongue, forming two principal rows, like the letter V, with its point turned backwards. Numerous large and soft papillæ, intermediate in form between the circumvallate and fungiform kinds, are situated behind, and on each side of, the circumvallate papillæ; they pass, towards the borders of the tongue, into irregularly notched and parallel ridges. Further back, these papillæ subside, and the mucous membrane becomes smoother and thinner, and is marked by numerous elevations and recesses, corresponding with the lingual mucous glands and follicles beneath it, some of which open into the bottom of the foramen cæcum.

The corium, or vascular part, of the circumvallate papillæ (fig. 70, *c*), and of the elevated rim by which each is surrounded, is prolonged into numerous secondary papillæ, which are buried in the thin and smooth epithelial covering. The fungiform papillæ likewise present numerous little conical secondary papillæ (*b*), covered by the epithelium. The filiform papillæ also have, at their points, numerous secondary papillæ (*a*), concealed in the thick brush of filamentous epithelium. Besides these secondary papillæ, found on the larger and so-called compound papillæ, numerous minute and simple papillæ, resembling the secondary papillæ, exist everywhere, between the compound papillæ.

Many of the muscular fibres of the tongue, pass into the mucous membrane and its papillæ, presenting the peculiarity of dividing and subdividing before they enter these parts. Both the compound and simple papillæ receive vessels and nerves. Each papilla contains one or many vascular capillary loops, according to its size. In the fungiform and circumvallate papillæ, especially, the nerves are very numerous, and, in the latter, very large; they are usually said to terminate in loops; but it is possible that many, at least, end by fine free extremities, a mode of termination seen in the tongues of some animals.

Each half of the tongue is supplied by three nerves. Of these, two are sensory, viz., the lingual or *gustatory* branch of the inferior maxillary division of the fifth cranial nerve, and the lingual branch of the glosso-pharyngeal. The former is distributed to the mucous membrane and papillæ at the forepart and sides of the tongue, the latter to the mucous membrane at the base and side of the tongue, and, it is said, especially to the circumvallate papillæ. The remaining nerve, the *hypoglossal*, or ninth cranial nerve, supplies the muscular substance of the tongue, and is the motor nerve of this organ.

The *soft palate*, its central depending *uvula*, and its lateral *arches*, or *pillars*, will be hereafter described with the other parts concerned in deglutition. Its mucous membrane, which is smooth and delicate, and provided with short soft papillæ, and numerous glands, is supplied by branches derived from the superior maxillary division of the fifth cranial nerves, and also by branches from the glosso-pharyngeal nerves.

Taste.

The true sense of taste in the tongue, is confined to the posterior third of the dorsum of that organ, the under surface of its apex, and a line along its edge, about a quarter of an inch wide. It is most marked on the hinder part of the organ. It also resides in the anterior pillars of the fauces, the soft palate near its attachment to the hard palate, and the hinder portion of the latter. (Stich and Klaatsch.)

The experiments of Reid show that the glosso-pharyngeal is a nerve of special sense, as well as of common sensation, and also an afferent reflex nerve; for not only are unmistakeable signs of pain produced by irritation of the nerve in the living animal, but division of this nerve, on the two sides, destroys

the power of taste in the parts of the tongue supplied by it. Division of the fifth cranial nerves, or of their gustatory branches, immediately produces loss of common sensibility in the anterior part of the tongue; for the application of caustic potash, or of a hot iron to this part of the organ, in the living animal, does not then give rise to any sign of pain. The power of taste in the forepart of the tongue, has also been said to be destroyed by division of the fifth nerve; but, as just mentioned, it would seem, that, except at its edges, and beneath its apex, parts which probably receive filaments from the glosso-pharyngeal, the forepart of the tongue is naturally destitute of the sense of taste. Hence the apparent loss of taste, after division of the fifth nerves, may have been only a loss of common sensibility in the animals experimented on, in consequence of which, sapid bodies no longer produced any signs of sensation, either common or special. There is an obvious difficulty, in determining very precisely whether an animal tastes or not. In cases of paralysis, in man, taste has been destroyed without the common sensibility, and the latter has been lost without the former. This would show, either that different nerves, or different filaments of the same nerves, minister to the two forms of sensation. Whilst it is certain, that the glosso-pharyngeal is a nerve of taste, the gustatory office of the so-called gustatory branch of the fifth nerve, is by no means so clearly established.

It has been observed, that in cases of paralysis of the facial nerve, above the origin of the chorda tympani, in the human subject, the sense of taste is much diminished, or even altogether lost. Experiments made by Bernard, on living animals, further show, that if the facial nerve be divided within the skull, the sense of taste is impaired on the corresponding side of the tongue; whilst the tactile sensibility remains unaffected. Division of this nerve, after it has issued from the stylo-mastoid foramen, does not, in any way, affect the sense of taste. Hence, the integrity of the chorda tympani, which is destitute of sensory fibres, appears to be essential for the proper exercise of taste. Perhaps the effects which follow its division, are owing to the diminution which then takes place in the secretion of the saliva.

A state of solution being an essential condition for the perception of gustatory impressions, sapid bodies are tasteless, when applied in a dry state, to a dry or coated tongue, and a free flow of saliva is of great use in the exercise of the sense

of taste. Contact of the sapid body being also essential, it is necessary, for very accurate tasting, that this contact be perfect; hence, a substance, if solid, must be pressed between the mobile tongue and the palate, so that, after it has undergone solution, it may diffuse itself over the whole of the gustatory mucous membrane. In this way, the savours of fruits, and the flavours of wines, become remarkably developed, after these have been carried over the whole of the mucous surface. A short time must elapse, after contact with the tongue, before sapid bodies excite the sense of taste. This varies according to the substance. Saline solutions are most quickly perceived, sweet solutions less quickly, then acid, and lastly, bitter substances. Even when mixed, different substances are tasted separately and consecutively. It is interesting to note, that the so-called colloid bodies which have a low, diffusive osmotic or dialytic power, are tasteless; whilst the crystalloids, which dialyse rapidly, are generally sapid. (Graham.)

Since many sapid substances, such as quinine and salt, are inodorous, the sense of taste must be regarded as independent of smell, as it is of touch, or of the sense of pain. But, in judging of the flavours of different substances, we are assisted by the organ of smell, for many flavours are incomplete without the help of the olfactory sense, and may be diminished by closing the fauces, so as to shut off the nose. The existence of nasal polypi also interferes with taste. Certain odours are undoubtedly confounded with taste. Thus, when eating garlic or vanilla, the sensations referred to the gustatory sense, are no longer perceived when the nose is kept closed. The vapour of chloroform, when inhaled through the nose, conveys the sensation of an odoriferous substance, although it is a sapid body. (Stich.) Deglutition necessarily assists in the appreciation of the taste of sapid substances, when these are grasped by the fauces.

The sense of taste is, in some respects, allied to the sense of touch. In the first place, it is not dependent on a purely special nerve, for the cranial nerves, through which this sense is exercised, are also common sensory nerves. All the parts concerned in taste, are also endowed with common sensibility. Moreover, for the perception of a gustatory impression, it is essential that the sapid body be brought into actual contact with some portion of the sensory surface, otherwise gustatory impressions cannot be excited. The same is true, however, of

the sense of smell, if we regard odours as material. Lastly, as in the case of touch, there is an absence of any complex recipient apparatus, the only structures entering into the formation of the gustatory surface, being the mucous membrane of the mouth, with its nervous and vascular papillæ, which closely resemble those of the skin, but are more delicate. The sense of taste differs, however, from that of touch, by being limited to a particular portion of the surfaces of the body, and, still more remarkably, by the peculiarity of its exciting causes, which are *specially chemical* and not mechanical agents. In this respect, as already mentioned in the section on Sensation in general, taste is evidently closely allied to smell. The organ of taste, indeed, shows greater resemblance to that of touch in structure, than in function. In both, the local application of the exciting stimulant, is necessary; but in the one, the action on the nerve is purely physical, and is merely transmitted mechanically, through the tissues which cover the nerve; whilst, in the other, the sapid substance must be fluid, or dissolved, must penetrate the tissues to reach the nerves, and must exercise some very special, and probably chemical, action upon them, so as to excite the nervous energy. Bodies differing widely, in both their physical and chemical nature, may excite allied tastes, as, for example, bitter saline substances and vegetable bitters. The causes of the sensation of taste, and of the sapidity or insipidity of different substances, are not further known; much less can we, at present, offer any explanation of the varieties of tastes excited by different sapid bodies. The sensations induced by them, however, are more distinguishable from each other, and therefore clearer, and more definable by language, than those of smell.

Certain properties of substances, which have been named the mechanical savours, such as the peculiar sensations communicated to the mouth, by oleaginous, amylaceous, or watery substances, are distinguished by the highly developed tactile sensibility of the tongue. They are due to the different degrees of consistency, presented by these bodies. The so-called mealy, sandy, pasty, astringent, and alkaline impressions, are probably merely special tactile impressions. Pricking, stinging, and biting sensations are perhaps modifications of pain, like the smarting of blistered surfaces. The burning, occasioned by some substances, as mustard, and the feeling of cold excited by others, as peppermint, are apparently referable to the sense of temperature; for both these impressions are independent of taste.

Some substances, when introduced into the mouth, only xcite tactile impressions, and hence are called *tasteless*; all nsoluble bodies belong to this class. Other substances, such s sugar, excite both tactile and gustatory impressions; and a hird class of bodies, such as smelling-salts and volatile oils, esides producing tactile and gustatory impressions, also excite orresponding odoriferous sensations; thus, again, showing he alliance between taste and smell. Lastly, some metals, vhen placed in contact with the mouth, produce no impression n the gustatory sense, merely exciting tactile and odoriferous ensations. Those substances which act on the gustatory ense, are called *sapid*. Of these, there are four different inds, viz., the sour, the saline, the bitter, and the sweet; artaric acid, common salt, quinine, and sugar, are examples f such substances. Solutions of sour and sweet substances, re said to be best distinguished, when they are applied to the ip of the tongue, whilst saline and bitter tastes are best pereived, when brought in contact with the root of the tongue. Acids and bitters are said to be the most readily detected of ll sapid substances; then saline, and lastly, saccharine. It has een found, that 1 part of sulphuric acid in 10,000 of water, nd 1 part of sulphate of quinine in 33,000 of water, can be etected, when carefully compared with pure water. (Valentin.) Sugar cannot be tasted, when there is less than 1 part in 80 r 90 of water; and of common salt, 1 part is necessary in 00 of water.

After the tongue has been exposed alternately, in succesion, to two or more allied tastes, the gustatory sense becomes lunted, losing its power of discriminating between them. This is probably due, in part, to some continuance of each impression on the gustatory nerves; but, it is perhaps principally ependent on small portions of the sapid bodies remaining issolved in the epithelial coat. The discriminating powers of he sense of taste, are, on the other hand, assisted by conrasting different flavours. If the tongue be exposed to a emperature much above, or much below, the normal temperaure of the body, both its tactile and gustatory sense become mpaired or suspended. Thus, after immersion of the tongue n a mixture of broken ice and water, or in water at a temerature of 125°, for about a minute, the taste of sugar cannot e perceived, and the tactile sensibility of the tip of the tongue s also diminished.

Gustatory impressions sometimes arise independently of the

contact of sapid bodies with the organ of taste. A drop o pure water placed on the tongue, gives rise to a slightly bitte taste; and the same sensation is caused by touching its surfac near the root, with a dry glass rod. A cool saline taste, some what resembling that of nitre, is produced by directing a smal current of air on to the tongue. (Henle.) Electricity als gives rise to gustatory impressions, a peculiar saline tast being caused, when the front of the tongue is stimulated b electrical shocks; whilst a constant current produces a sou taste at the positive pole, and an alkaline impression at th negative pole, perhaps from decomposition of the secretions o the mouth. Indistinct gustatory sensations may be induce by striking sharply and lightly the lingual papillæ. A mechanical stimulus applied to the fauces and root of th tongue, induces a bitter taste, and a sensation of nausea.

The sense of taste presents different degrees of developmen in different individuals, being, in some, much more acute tha in others. Like the other senses, it is improved by cultiva tion, as is well seen in the case of wine- and tea-tasters. I colds, and diseases and injuries of the brain, the sense of tast is lost, either temporarily or permanently.

Impressions made upon the sense of taste, remain for certain time; those produced by some substances, lasting for considerable period. As a rule, they endure longer than th after impressions of smell, hearing, or sight. The after tast or *arrière gout*, has its seat at the root of the tongue; lik taste, it can be strengthened by pressing, rubbing, and movin the sapid body between the palate and the tongue. The afte taste frequently differs from the original one; a bitter substanc may give rise to a sweet after impression, or a sweet substanc to a bitter one.

Subjective gustatory impressions sometimes occur, as, fo example, metallic, sweetish, and sanguineous or nauseou tastes. These subjective sensations have been supposed t proceed from changes in the composition of the blood, whic are perceived in the interior of the organ of taste. They ma be due to errors in the circulation through the nervous centre connected with taste; and sometimes merely to an altere condition of the secretions of the mouth. A person sufferin from the disease known as saccharine diabetes, in which suga exists in undue quantity in the blood, is not, however, con scious of a sweet taste, and can readily distinguish sugar whilst a taste of blood is usually only experienced when th cavity of the mouth contains blood.

The sense of sight, as is well known, materially influences he gustatory sense; for, in the dark, sapid substances lose half heir relish.

The uses of the sense of taste are, besides that of imparting gratification, chiefly to assist in the choice of food. This is ften peculiarly manifested in invalids or convalescent persons.

The Organs and Sense of Taste in Animals.

Amongst the *Vertebrata*, the sense of taste is probably well developed n all Mammalia, most of which masticate their food, and so retain it ong enough in the mouth, to enable it to act as a sapid body. The hief organ of taste is the tongue, but the soft palate, as in Man, may e supposed to be likewise concerned in this sense. The dorsum of the ongue is generally very rough, and frequently presents horny papillæ, r, as in the Carnivora, horny recurved spines, which aid in grasping he food in mastication, or even in rasping flesh from bones, and in leaning the coat of the animal itself; but the surface at the root and dges, is softer, and is probably more actively gustatory. The shape of his organ presents many and striking varieties. In some of the suctorial bats, it is singularly modified, presenting a circular series of elevaions, provided with proper muscles, and forming a sucking organ. In the nt-eater, it is long, slender, and worm-like, and can be protruded, with reat swiftness, for a distance of sixteen or eighteen inches. The ongue of the Cetacea generally, is broad, and only slightly moveable; in he herbivorous species, Sirenia, it has a complicated papillary surface; ut in the zoophagous kinds, or true Cetacea, it has neither circumvallate or conical papillæ, but merely minute tactile papillæ; it has been doubted, whether these animals possess the sense of taste. Some Mammalia have second, or even a third, accessory tongue, as, for example, the bears.

The organ and sense of taste, appear to be incompletely developed in *Birds*, which, for the most part, swallow their food quickly, and indeed, eem to be rather guided in their choice of it, by the sense of sight. The tongue usually has a horny covering at its tip, and is destitute of papillæ, except near its base. In the parrots, however, the tongue is oundish, large, and fleshy, and is covered with papillæ; in the flamingo, t is also large, soft, and papillated. In a few species, it is cleft at the oint, as in the ravens. This organ often presents peculiarities conected with its use in the taking of food; thus, in the humming bird, it s rolled into a sucking tube, and terminates in hair-like filaments for etaining the nectar of flowers; in the toucan, it is fringed with bristly rocesses for trying the ripeness of fruit; and, in the woodpeckers, it s barbed with inverted processes for seizing insects.

In Reptiles, the tongue also appears to be rather a tactile than a ustatory organ, for they almost all swallow their food immediately it as been seized; so that the sense of taste is probably quite subordinate. The chameleon has a very large tongue, which, when protruded, s worm-like in shape; it possesses a central canal, and terminates nteriorly, in a club-shaped extremity, smeared over with a viscid secreion; when darted out after prey, it appears longer than the whole ody of the animal. In the crocodiles, the tongue is closely attached to

the floor of the mouth; but in the chelonian reptiles, it is free. The turtles have a small and hard tongue; in the land tortoises, it is soft and papillated, and is undoubtedly endowed with gustatory sensibility. In the Ophidia, and in the small lizards, the tongue is bifid, and is lodged in a sheath, from which it can be protruded with a darting, quivering motion.

Amongst the Amphibia, the tongue is soft; it lies inverted in the mouth, both in the frog and toad, and is used as a prehensile organ. The structure of the lingual papillæ, and especially the mode of termination of their nerves, have been closely studied in the frog. By some, it is held, that, in the large fungiform papillæ, the nerves end in fine fibres, which are attached to the bases of the large terminal nonciliated epithelial cells, whilst the ramified muscular fibres join the ciliated epithelium at the base of the papillæ. (Stilling, Waller.) It has also been stated, that the nerves end in narrow cells, or rods, which pass up to the surface, between the true epithelial cells. (Axel Key.) We shall find a similar structure, and this is an interesting fact, in the olfactory mucous membrane of the nose. The less perfect Amphibia, such as the proteus and siren, appear to be destitute of a tongue.

In Fishes generally, the sense of taste is probably but imperfectly developed, even if it exist. Some, indeed, have no tongue at all; for they bolt their food instantaneously, as it is taken, so that the gustatory sensibility, if present, must be seated in the palate and fauces. Others possess a large tongue, which presents prehensile teeth rather than sensory papillæ.

A sense of taste, or, at all events, a power of discriminating proper food, would seem to be present in most, if not all, of the non-vertebrate animals, even in the Infusoria, many of which appear to exercise a faculty of selection in regard to their food. The seat of this sense is probably here too in the neighbourhood of the entrance of the digestive apparatus; but its proper organ or organs are unknown. The so-called tongue of the Cephalopods, and the odontophore of the Gasteropods, are rather accessory digestive than gustatory organs. The larvæ of insects, the feeding propensities of which, are so strong and peculiar, nevertheless present no special organ of taste.

THE SENSE OF SMELL.

The Organs of Smell.

The nasal cavities, or *nasal fossæ*, situated between the base of the cranium and the roof of the mouth, at the upper and fore-part of the face, are the seats of the organs concerned in the sense of smell. The roof, sides, and floor of these cavities, are formed by the surrounding bones of the cranium and face, see fig. 72. The ethmoid bone, which forms part of the floor of the cranial cavity, is, however, the most immediately concerned in the formation of the olfactory part of the nasal fossæ; its cribriform plates, fig. 72, enter into the formation of the

oof; its cellular lateral portions, 3, constitute the convoluted ides of the upper part of the cavity; whilst its median septum, , assists in forming the partition which divides one nasal fossa rom the other. The fore-part of the fossæ is completed, at the ides and in the median line, by the nasal cartilages, fig. 71, , which are adapted to the margin of the great nasal aperture een in the bones, as well as to the bony septum. These cartiages give form and stiffness to the visible part of the nose; hey are provided with certain small subcutaneous muscles. The nasal fossæ open anteriorly, by the apertures called the *anterior nares*, or nostrils, which are provided with short hairs, or *vibrissæ*, to prevent the introduction of coarse foreign bodies. Behind, the fossæ open, by two orifices, called the *posterior nares*, into the upper part of the pharynx, see fig. 73. The

Fig. 71.

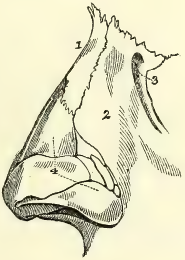


Fig. 71. Lateral view of the bones and cartilages of the nose. 1, left nasal bone. 2, ascending part of the superior maxillary bone. 3, lachrymal groove for the lodgment of the lachrymal sac. 4, cartilages of the side, and alæ of the nose. (Arnold.)

side of each fossa, next the middle line or *septum* (fig. 72, 4, 5) is smooth, but the outer side is more or less convoluted, owing to the presence of three delicate, shell-like bony expansions (fig. 73), viz., the upper, 2, and middle, 3, turbinated portions of the ethmoid, and the lower independent turbinated, bone, 4. Below each turbinated bone, is a longitudinal recess, named a meatus. These three *meatuses*, named *superior*, *middle*, and *inferior*, communicate with certain cavities, called *sinuses*, formed in the ethmoid, sphenoid, frontal, and upper jawbones.

At the anterior nares, the skin which covers the nose

externally, is continuous with a lining membrane, called the *nasal mucous membrane*, *pituitary*, or *Schneiderian membrane*, which lines the interior of every part of the nasal fossæ, and secretes a fluid named *pituita*. This membrane, besides being continuous with that lining the pharynx and the Eustachian tubes, is also extended into the several sinuses just mentioned; moreover, it is prolonged, on each side, through a small canal, leading from the nasal fossæ, into the lachrymal sac, and thus becomes continuous with the *conjunctiva*, or mucous membrane of the eyelids.

The nasal mucous membrane varies in different regions. First, there is a *lower* region, in the neighbourhood of the

Fig. 72.

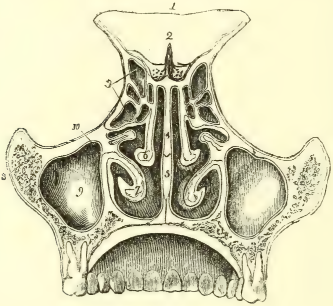


Fig. 72. Transverse vertical section across the nasal cavities, opposite to the middle of the hard palate; the anterior section, seen from behind, so that the hinder surface of the upper teeth is seen below. 1, part of inner surface of cranium. 2, projection between the two cribriform plates of the ethmoid bone. 3, cells in the left lateral mass of the ethmoid bone. 4, median septal portion of the ethmoid bone; the narrow dark space on each side of this, is the olfactory region. 5, the vomer, or bony septum nasi. 6, the middle turbinated portion of the ethmoid. 7, the left turbinated bone. 8, section of the malar bone. 9, maxillary sinus, or antrum of Highmore, which communicates with the nasal cavity. (After Arnold.)

nostrils, in which the mucous membrane is firm, pinkish-white in colour, provided with fine papillæ, and covered with a squamous epithelium, consisting of several layers of cells. Secondly, there is a *middle* region, in which the mucous membrane is dark-red, soft, provided, in places, with numerous little mucous glands, and covered with a cylindrical, or columnar

liated epithelium. Thirdly, there is an *upper* region, very *urrow*, from side to side (see fig. 72), and corresponding ith the roof, and the ethmoidal portion of the convoluted les and septum, where the mucous membrane is pulpy, of yellowish-brown colour, provided, in its upper part, with culiar short glands, somewhat like the sebaceous glands of e skin, and covered with cylindrical or columnar epithelial lls, having flattened ends, but being destitute of cilia. etween the cells of this epithelium, are found other, finer, indle-shaped columns, or rods, which are of a varicose shape, id project beyond the surface; they are named the *olfactory lls*. (Schultz.) Lastly, the various sinuses connected with e nasal fossæ, are lined by a thin, red, smooth, ciliated mucous embrane. The lining membrane of the lower region next the nostrils, is usually dry; whilst that of the other two gions, and of the sinuses, is constantly moist, either with mple mucus, or with the special secretion of the small glands the upper region. The lower region is also the thinnest, id least vascular; the sinuses are much more so; whilst ie upper and middle regions are thicker and more vascular, specially over the turbinated bones.

The nerves supplying the nasal mucous membrane, are erived from three sources. First, from the nasal and anterior ental branches of the fifth pair of cranial nerves, which are istributed to all its parts; secondly, from the vidian, naso-alatine, descending palatine, and spheno-palatine branches f the sympathetic nerve, which also probably have a general istribution; thirdly, there are the terminal branches of the rst pair of cranial nerves, or *olfactory nerves*, fig. 73, 2. he latter proceed from the olfactory lobes, 1, within the cra-ium, and pass through the small openings in the sieve-like lates of the ethmoid bone, to gain the upper part or roof of he nasal fossæ. They are about twenty in number, and are rranged in each fossa, in three groups, one, which supplies the oof, another distributed on the surface of the cellular part of he ethmoid bone, 2, 3, as low down as the middle turbinated one, whilst an inner group spreads out on the upper third f the nasal septum. The branches of these nerves, every-where form a close net-work; they are composed of small, oft, nucleated, grey, or non-medullated nerve fibres, having o white medullated fibres amongst them; their ultimate ibrillæ are said, by Schultz and others, to join the rod-like odies, named the olfactory cells, which are found between the

ordinary epithelial cells. Through these cells, which are regarded by Schultz as nervous structures, or bi-polar nerve-cells, the ends of the olfactory nerves are believed to reach the very surface of the membrane, in the form of delicate threads, which project between the ordinary epithelial cells, and are kept constantly moistened by the secretions of the part.

Of the three regions of the nasal fossæ, the upper one alone, which corresponds with the narrow part to which the olfactory nerve is distributed, is the true *olfactory region* or *seat of smell*; the middle region, ciliated like the rest of the air-passages, may be regarded as the *respiratory part* of the nose,

Fig. 73.

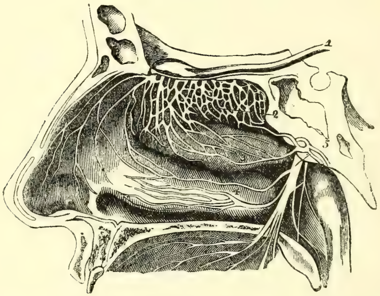


Fig. 73. Vertical section through the right nasal fossa, showing the outer side of that fossa, with a part of the base of the cranium, the palate, and the nose. 1, the olfactory tract ending anteriorly in the olfactory lobe, or bulb, resting on the cribriform plate of the ethmoid bone. 2, superior turbinated portion of the ethmoid bone, corresponding with the upper part of the olfactory region, and covered with the network of the branches of the olfactory nerves. 3, middle turbinated portion of the ethmoid bone, covered with a few olfactory nerves, and also forming part of the olfactory region. 4, lower turbinated bone, receiving only branches of the fifth nerve, 5, which also supplies the palate. The anterior region of the nasal fossa receives branches also derived from the fifth nerve. (After Arnold.)

which organ, indeed, is placed, for obvious purposes, in the track of the respiratory passages; the lower region is the common aperture to the two others, and, being nearer the surface, is more cutaneous in its character. The region of the sinuses is not directly concerned in smell; but these cavities may act as reservoirs for odorous emanations, so as to

prolong olfactory impressions; they chiefly aid, however, in providing moisture for the interior of the fossæ. Even the lachrymal secretions, or tears, having performed the office of moistening the eye-balls, pass, through the canal already mentioned, into the nasal fossæ, and serve a similar purpose.

Odours.

It is not yet known why certain bodies are odorous, and others not. As regards the physical condition proper to odorous bodies, it is certain, however, that most, if not all, are volatile, or else actually aëriform or gaseous, at ordinary temperatures; but all volatile bodies, or bodies capable of assuming the form of vapour, are not necessarily odorous, as, for example, water. Certain bodies, or fine particles of them, conveyed mechanically through the air to the nose, may cause smell, either on being dissolved in the fluids of the nose, or by being previously volatilised, or by giving off odorous effluvia, which are then dissolved in the fluids of the nose.

The chemical constitution of odorous bodies, offers no certain explanation of this peculiar quality. For example, some elementary substances, as chlorine and copper, produce the sensation of smell, whilst others, as nitrogen and silver, do not; again, of allied chemical substances, such as the salts of copper and silver, the former are odorous, whilst the latter are inodorous. As a rule, imperfectly oxidised substances, or those which have a tendency to further oxidation, such as essential oils, have a strong odour; but even a most perfectly oxidised body, such as carbonic acid, possesses an odour, though this may rather depend upon its irritating property, when it is of a certain strength; for, if diluted, it has no smell. Many perfectly oxidised bodies do not smell at all, as, for example, water; some smell very slightly, as sulphuric, phosphoric, and chloric acids. Hyper-oxygenated bodies, if volatile, as peroxide of hydrogen, produce a peculiar odour, but not if they are fixed, like the peroxides of barium and manganese. Ozone, whether it be a polarised condition of oxygen, of oxygen combined with itself, or in some other state, possesses a very remarkable pungent odour. It is remarkable, that hydrogen, the lightest and most diffusible element with which we are acquainted, produces, when in combination with all other elements, excepting oxygen, the most powerful odorous bodies with which we are familiar. Thus, with nitrogen, it forms

the pungent substance, ammonia; with chlorine, hydrochloric acid; with cyanogen, a hypothetical radical composed of carbon and nitrogen, both of which are inodorous, hydrocyanic acid; with carbon only, the carburetted hydrogens (coal-gas, and marsh-gas); with phosphorus, phosphuretted hydrogen; and with sulphur, sulphuretted hydrogen. All these compounds are relatively unstable, and prone to oxidation. With oxygen in equal proportions, hydrogen forms the inodorous, though volatilizable body, water.

Although, then, neither the physical nor the chemical conditions of matter, which are distinctive of odorous bodies, can be clearly defined, volatility on the one hand, and a condition of chemical instability, especially that of imperfect oxidation, on the other hand, are probably the two most general characteristics of odorous bodies.

If the cause of odour generally is but little known, still less are the *qualitative* characters of different odorous bodies, and the causes of the varieties of smell, understood. In this part of the inquiry we are met with singular perplexities and contradictions; thus, bodies differing much in nature, have similar kinds of odour; as, for example, garlic and the vapour of arsenic, as this becomes changed into arsenious acid; phosphorus, also, has a garlicky smell. At present all attempts to classify odours are futile. The *quantitative* power, or intensity of odour, in certain bodies, is very remarkable. It is very intense, and capable of propagation to great distances, in the case of camphor, turpentine, ether, and musk; whilst, on the other hand, it is feeble, and acts only at short distances, in the case of caoutchouc, gum, or sugar, the odours of which latter substances may be due even to associated aromatic impurities.

The extreme *divisibility* and minuteness of the ultimate odorous particles, is evidenced in such facts, as that a drop of ether will impregnate the atmosphere of a large apartment, and that a grain of musk has been kept for ten years, emitting constant odour, without, it is said, suffering any appreciable loss of weight. This fact has been quoted in support of an idea, that odours are not caused by material emanations from the odorous substance, but perhaps by subtle motions, or undulations, of a peculiar kind, originating in the odorous bodies themselves, and exciting similar undulations in the atmosphere, or in some special medium, which, impinging on the olfactory nerves, produce the sensation of smell. But for such an experiment to be conclusive, the hygrometric condition of the

musk, at the commencement and end of so long a trial, should be accurately determined, otherwise it becomes quite valueless, even though other many obvious causes of fallacy be eliminated. Moreover, strongly odorous bodies, such as turpentine or ether, do positively waste, so that the inference, at present, is in favour of the actual transmission of material particles through the air, until they are brought into contact with the nasal mucous membrane. The interposition of a solid body between an odorous substance and the nose, prevents the transmission of the odour, which, therefore, cannot be conducted, like sound, by vibrations, nor, like light, by undulations. Odorous emanations are capable of being absorbed by porous substances or materials, such as cloth, especially, it is said, by dark cloths, which are therefore unsuited for medical men and nurses in fever hospitals. When absorbed by fresh animal charcoal, odours are, like the compound gases, partially subjected to decomposition by a process of slow oxidation.

Smell.

Every portion of the nasal mucous membrane possesses common sensibility and its modifications, being alike capable of receiving impressions of touch, temperature, and pain. This is owing to the presence of the branches of the fifth pair of nerves. It is probable even, as already hinted, in speaking of carbonic acid, that many strong vapours, such as ammonia, acetic, and other volatile acids, not merely affect the true nerve of smell, but also the branches of the fifth nerve, causing that combination of odour and irritation, which characterises the so-called *pricking* or *pungent* odours. These substances appear indeed, to act, when highly diluted, as odours, but when less diluted, or concentrated, as irritants, just as they act on the cutis, and excite a pricking or smarting sensation when the cuticle is removed.

The sense of smell proper, however, is shown, by the following facts, to be dependent on the action of the olfactory nerves, and of the special olfactory lobes or centres. First, the size of these nerves and lobes, in animals distinguished for their perfect sense of smell; secondly, the abundant distribution of the nerves in the upper part of the nose; thirdly, the absence of the sense of smell in congenital deficiency of the olfactory lobes and nerves, of which an instance occurred in a street scavenger at Leipsic; fourthly, the loss of the sense of smell in diseases

affecting the olfactory lobes, and the upper or olfactory region of the nose; and lastly, the similar loss of smell, following the division or destruction, of these lobes in animals. This experiment is most easily performed in young animals. (Biffi.)

It was found by Magendie, that dogs in which the olfactory nerves had been destroyed, still searched for, and discovered, meat. This fact, he thought, justified the extreme conclusion that the olfactory nerves were not in any way concerned in smell; but it is rather to be explained, by reference to the instinct and habits of the dog, which would lead it to search for food, even though it could not smell. Paralysis of the fifth cranial nerve, diminishes the healthy secretion of the nasal mucous membrane, and so interferes with the sense of smell.

The *conditions* necessary to smelling, are these. First, the transportation through the air of the odorous particles, in the manner already mentioned, to the nose; this is more rapid when the air is in motion, and takes place in the direction of that motion. Secondly, the solution of the odorous particles in the moisture of the olfactory mucous membrane. Thirdly, their passage, by means of diffusion, into the substance of the extremities of the olfactory nerves, which, as already mentioned, approach to, or even reach, the epithelial surface. Fourthly, the particles must exercise a chemical action upon the extremities of the nerves; and there are reasons for supposing that the presence and action of oxygen, in conjunction with the odorous substance, are necessary to this process. (Graham.) Fifthly, the nerve itself must be endowed with the property of receiving such substance, or its resulting compounds, and of being chemically acted upon by them. Sixthly, the olfactory lobes must be capable of discriminating the effects of the special impressions excited at the extremities of the nerves. Lastly, the nasal cavities must contain air; for, in man, and probably in all air-breathing animals, the sense of smell fails in the water; and according to Weber, when water, or even solutions of odorous substances, are poured into the nose, smell is temporarily suspended. These effects have been referred to abnormal changes in the epithelial and other cells of the nasal mucous membrane.

The physical conditions necessary to the exercise of smell, are influenced by the respiratory movements, and by the state of moisture of the nasal mucous membrane. Inspiration is obviously necessary to smell, as the means of drawing the

odorous particles into the nose. In ordinary expiration, smell is almost entirely absent; but if the mouth be filled with tobacco smoke, or the vapour of chloroform, and this be forced from the pharynx, through the posterior nares, into the nasal fossæ, its characteristic odour is at once, though less distinctly, perceived. The act of inspiration is, however, essential as a mechanical aid; for holding the breath prevents the exercise of the sense of smell. In gentle inspiration, odours are faintly perceived; in strong, quick inspirations, as in sniffing, to appreciate the odour of wines or flowers, or very faint odours, they are most acutely perceived, because a larger quantity of the odorous substance, passing by the middle and lower regions, impinges, in a given time, with a certain force, upon the olfactory region; the upward direction of the stream of air thus inhaled, carries it at once to that part of the nose. Hence, too, closing one nostril diminishes the force of odorous impressions. The presence of large polypi in the nose, destroys smell. In quiet breathing, the air passes chiefly through the lower and middle regions of the nose, viz., through its respiratory portion, and only a limited quantity reaches the upper or olfactory region; whilst, in stronger inspirations, the stream of air is drawn upwards, a movement said to be favoured by the form of the inferior turbinated bones.

The natural moisture of the mucous membrane is indispensable to the exercise of smell. The secretion of the nasal glands is abundant; it is slightly alkaline, but otherwise its nature is unknown. From the depth, protected character, and position of the *olfactory region*, out of the course of the respiratory air-current, its moisture is preserved from evaporation; this is also checked by the copious supply of mucus from the nasal fossæ and their communicating sinuses, and by the continuous lachrymal secretion. These fluids also serve to charge the inspired air-current, with a due proportion of moisture. The necessity for the moist condition of the olfactory membrane, is shown by the absence of smell when this is more than ordinarily dry, as in certain stages of a cold. In perfectly dry air, odours are perceived with difficulty. The opposite condition, of too great an amount of moisture, as in other stages of a cold, is also unfavourable to smell. The deficiency of smell, noticed after certain surgical operations, in which the nerves regulating the secretion of the nasal mucous membrane have been divided, may also be due to the unusual state of dryness of the membrane, which ensues under

those circumstances. In all these abnormal conditions, however, the loss of smell may be owing to inflammation, or some other change in the membrane or its nerves.

In reference to the necessity for the presence and co-operation of oxygen for the exercise of the olfactory sense, and for some oxidation of the odorous substance on the surface of the nasal mucous membrane, it has been stated, that odours are imperceptible, when inspired mixed with carbonic acid or nitrogen; but, in the former case, the excitability of the olfactory nerves may be suspended by the specific action of the carbonic acid; and, in the latter case, careful observation has shown, that some sense of smell is still retained. This, however, may be due to oxygen already dissolved in the fluids of the nose; and it is difficult to inhale pure nitrogen sufficiently long, to avoid this source of fallacy, without risk to life. The remarkable pungency of ozone, suggests the possibility, that, even if odorous substances be not oxidised at the surface of the membrane, and so, whatever their nature, be rendered soluble in the nasal mucus, yet ordinary oxygen may operate as a special stimulant to the excitability of the olfactory nerves, and thus increase the intensity of the sensation.

Whether odorous substances are first oxidised or not, some *chemical reactions* probably occur between them and the substance of the olfactory nerves; and these reactions, of the nature of which we are entirely ignorant, are probably, moreover, of some special nature, in the case of each distinct odour. In this way, we might account for the differences between different smells. Various irritants, such as mustard, and acetic acid, produce quite similar impressions upon the nerves of common sensation, as, for example, when they are applied to the denuded cutis; but these two substances, and all others having different odours, produce distinct impressions of smell. Hence, not only do different odours, most likely, produce different chemical effects on the olfactory nerves, but these nerves, and their nervous centres, must experience special physiological reactions in the discrimination of different odorous substances. Our knowledge concerning this apparently very simple sense is, however, extremely limited.

It has been said by some, but is doubted by others, that mechanical irritation can produce odorous impressions on the olfactory nerves. Direct mechanical irritation of the olfactory nerves, causes neither pain nor reflex movements; but irritation of the nasal branches of the fifth pair, is followed by pain and

reflex movements. The galvanic or other form of electrical stimulus, produces a sensation of tickling, and sneezing. It has been said that galvanism excites an ammoniacal smell, when the negative pole is applied to the olfactory membrane, but an acid smell, when the positive pole is employed. (Müller.) These effects may be owing to chemical decomposition of the mucus; and, according to general authority, the electrical stimulus does not directly excite the special properties of the olfactory nerves.

The *acuteness* of smell, in regard to certain substances, is very remarkable, $\frac{1}{33,000}$th part of ammonia, $\frac{1}{200,000}$th part of bromine, $\frac{1}{1,000,000}$th part of sulphuretted hydrogen, and even $\frac{1}{13,000,000}$th part of musk, being perceptible when mixed with common air. Odorous impressions are quickly blunted, and are of very short duration. It has been conjectured, that we do not perceive double sensations of smell from the two nostrils, because of the plexiform arrangement and non-medullated structure of the olfactory nerve fibres; but, to this, it may be objected, that we can, by attention, discriminate the sensation conveyed through each nostril, even when the same odour is presented to both; and, moreover, when different odours are presented to the two nostrils, we do not perceive a combined impression or sensation; but each smell is alternately, or separately, perceived. The olfactory sense, like the other senses, varies in different persons, both as to its quantitative and qualitative character, some having the sense obtuse, and others acute, in regard to all odours, some discriminating particular faint odours, as those of certain flowers or fruit, and others not being able to perceive them. The sense may be trained, by exercise and attention, alternating with due intervals of rest, and abstinence from the action of the same odour. On the other hand, it may be blunted, by the habitual presence of any one odour, at least, as regards that odour itself. Why certain odours are agreeable, and others disagreeable, to persons generally, is not known; in the case of individuals, the utmost diversity prevails in this respect, habit especially, being a second nature.

Whether *after smells* due to states of the nerves, occur similarly to after tastes, is difficult to decide, for particles of odorous substances retained on the mucous membrane, may cause prolonged sensations. Subjective sensations, due to changes in the composition of the blood, or to disturbances in the circulation through the olfactory nervous centre, have been less commonly

observed in regard to smell than to the other senses. Maniacal persons, however, often complain of disagreeable odours.

The sense of smell is allied, not only by its chemical and physical phenomena, but also physiologically, to the sense of taste. It ministers but little to the intellectual faculties of man, but rather to his bodily wants, aiding him in determining his choice of food, and of such products of the animal, vegetable, or mineral world, as are agreeable to this particular sense; and often teaching him to avoid injurious or disagreeable substances, especially gases and vapours. It is, in particular, the sanatory sense, serving to test the air we breathe, and, if duly attended to, warning us of the deleterious emanations from decomposing organic matter.

Smell is very acute in certain uncivilised tribes, as amongst the Peruvian Indians, who can distinguish, by it, in the dark, persons of different races. It is recorded of James Mitchell, who was born blind and deaf, and was necessarily dumb, that he could distinguish persons, and recognise strangers, by the sense of smell.

The Organs and Sense of Smell in Animals.[1]

The sense of smell is undoubtedly very generally possessed by animals. Besides being a source of enjoyment, and serving the important office of aiding animals in the pursuit of living prey, and in their search after, and selection of, other proper food, the sense of smell often assists them in the avoidance of their natural enemies, likewise informs them of the presence of individuals of their own species, and, as in Man, doubtless frequently warns them of the existence of noxious vapours, and other substances.

This sense exists, in a more or less highly developed state of perfection, in all the Vertebrata, whether they breathe air or respire in water, for it is present even in all fishes. But, as we know and understand smell, it is, in its highest degree, an atmospheric sense, and, in fishes and all lower aquatic animals which possess it, must exist in some modified, and probably less refined, though acute, form. In a very few of the Cetacea, alone amongst the Vertebrata, is this sense entirely wanting.

In all the air-breathing Vertebrata, *i.e.*, in Mammalia, Birds, Reptiles, and the perfect Amphibia, the olfactory organs, however highly or simply developed, are situated in the course of the respiratory passages, the nasal fossæ being, in all cases, pervious backwards, opening behind, usually into the upper part of the pharynx, but, in the very lowest forms, into the mouth. In the Mammalia, the nose is, as a rule, highly developed; the nasal fossæ are capacious; the horizontal cribriform plate and the lateral cellular parts of the ethmoid bone are large, and, as well as the turbinated bones, often highly complex; the various sinuses in the adjacent bones are well developed, though they are not

lirectly concerned in the sense of smell. The anterior part of the nose s cartilaginous, and is provided with muscles; it forms the so-called nuzzle of the dog, the snout of the pig and tapir, and the trunk of the lephant. In the seals, walruses, beavers, and other diving mammals, he nostrils are slit-like, very moveable, and capable of being tightly losed at will; a similar provision is met with in many burrowing nimals; and in the camels, also, the large moveable nostrils can be losed against the tornado of the desert. In many bats, the nose is leveloped into singularly formed folds or leaflets, which are supposed o collect odours. But perhaps the most remarkable modification of the nterior part of the nose, is the elephant's trunk, which is a double tube, ontaining thousands of muscular bundles, and is not only a prehensile rgan, and a hydraulic pipe, but forms the usual respiratory passage. n this animal, besides the ordinary adjacent sinuses, which are very arge in the frontal bones, there are others in the temporal, parietal, nd occipital bones, all of which communicate with each other.

In certain carnivorous animals, as in the dog and seal, and also, but iot to such an extent, in many Ruminants, as in the sheep and deer ribes, in all of which the sense of smell is very acute, as witnessed in he quick recognition of the presence of Man exhibited by the stag, and n the almost fabulous power of certain dogs in following the scent of heir prey upon the ground, provision is made for a vast extension of the asal mucous membrane, by a most singularly complex lamination of the pongy bones, constituting the structure named the *labyrinth*. The lfactory nerve is not, however, commonly distributed over this comlicated portion of the nose, so that it only indirectly subserves the lfactory sense. Possibly it delays, retains, and subdivides the atmophere, laden with odorous matters, in its intricate passages, and so acilitates their oxidation; or it may be intended to aid in warming and noistening the air. In the Cetacea, the nasal cavities are reduced to imple, long, narrow canals, destitute of turbinated bones, and having o adjacent sinuses. As in the rest of the Mammalia, the posterior ares open into the pharynx, but the anterior nares, instead of being laced near the extremities of the upper jaw, are found far back on the op of the head, where they form, sometimes, as in the sperm whale and arwhal, one, but usually two, blow holes, through which the water, aken in by the mouth in feeding, and stored up in two strong muscular avities, can be forcibly expelled. The high position of these openings eadily brings them to the surface, when the animal desires to breathe, n act which can be accomplished, even whilst the mouth is submerged nd engaged in catching prey. The nasal fossæ of the Cetacea, exposed, s they are, to the frequent passage of water through them, as well as f air, have little or no concern in the function of smell. Thus, in the rue whales, the olfactory nerves are proportionally very small, and, udging from what takes place in ourselves, when water, or even soluons of odorous substances are poured into the nose, it may be conjecured that they do not distinguish the presence of odorous particles in ne water, but only that of those conveyed to them through the air aken in during inspiration. In the porpoises and dolphins, however, ne olfactory nerves are absolutely wanting, and these creatures, thereore, can possess no true sense of smell, though they, and indeed the

other Cetacea, may receive impressions of an irritating character from substances diffused through the water, acting on the extremities of the branches of the fifth pair, which, as usual, supply the nasal mucous membrane.

Amongst *Birds* generally, the sense of smell does not appear to be so highly developed, as to qualitative power in the individual, though it may be as acute as in Mammalia. There is no longer a cribriform plate to the ethmoid bone, for the olfactory nerves pass each through a single foramen. The nasal cavities are proportionally smaller and less complex in their interior, than in the Mammalia, but the turbinated bones are sometimes convoluted, and even laminated. The posterior nares often coalesce before they open into the pharynx. The anterior nares are never provided with moveable cartilages, as in the Mammalia. These openings differ much in size, position, and structure; they are generally wide and open, but are narrow in the heron, often protected by stiff feathers, as in the crows, or covered by a scale, as in the rasorial birds; they are usually placed on the sides of the bill, but sometimes at its base, and occasionally, as in the apteryx, at its apex. Judging from the relative size of the chief turbinated bone, and of the olfactory nerves, the wading birds appear to possess the most perfect sense of smell. In the vultures, also, the nose is much prolonged, and the olfactory nerve is large; they are said to smell carrion at very great distances. Nevertheless, the idea still sometimes entertained, that the vulture scents its dead prey from the enormous altitudes at which it flies, has been disproved, the discovery of its food being effected through the agency of vision.

In *Reptiles*, the sense of smell seems to be less developed than in birds; there are few or no complications of the surfaces of the nasal fossæ. The posterior nares open, in the Saurians, into the pharynx; but in the Chelonia and Ophidia, through the palate, into the mouth. In the crocodiles, the nostrils can be closed when the animal is beneath the water; and these apertures being placed at the end of their long snout, they are able to lie almost completely submerged, concealed, and watching for their prey.

The perfect *Amphibia* also present two posterior nares, opening through the palate into the mouth; but in the Proteus family, this opening is placed so far forwards, that it passes through the upper lip; in the Proteus itself, the nasal mucous membrane is plicated, as in Fishes. In their early fish-like larval condition, the organs of smell, in the Amphibia, are merely simple depressions or recesses, like these parts in fishes, but they are provided with cilia.

The sense of smell is probably, as already stated, somewhat modified in aquatic animals; but it is, nevertheless, judging from the size of the olfactory nerves and lobes, actively exercised in *Fishes*. These animals do not inhale the atmosphere into their bodies, for they have no lungs. The nasal fossæ form two blind recesses or culs-de-sac, opening externally on the fore part of the head, but, in almost all cases, shut off posteriorly from the mouth or pharynx. The water, through which medium the odorous particles must be transported, enters these nasal culs-de-sac, and there comes in contact with the delicate membrane supplied by branches from the large olfactory lobes. This membrane

ten has its surface increased, by being thrown into variously folded plaited laminæ, sometimes forming longitudinal, and sometimes ıgularly complicated radiated, plicæ.

In the Cyclostomata, the nasal apparatus is single, and is sometimes osed at the bottom; but in the Myxinoids, for example, the cavity is olonged backwards, by a special trachea-like canal, which perforates e palate, and is there provided with a membranous valve, which can opened or shut. The lepidosiren is another example of the commucation of the nose with the mouth, in fishes. In the minute and nple amphioxus, the nasal cul-de-sac is single, median, very superial, and ciliated in its interior.

The Mollusca, being chiefly aquatic, must receive odours through the ıter. In the Cephalopods, the organs of smell are supposed to be two vities, placed near the back of the eye, each containing a papilla; the rves which pass to them arise from the side of the optic nerve or nglion, and perforate the cartilaginous capsule of the eye, before tering the papillæ. The cuttle-fish is said to exhibit a strong averon to certain odorous bodies. It has been suggested, that the smaller ccal tentacles of the nautilus, are possibly connected with the sense smell. In the other Mollusca, the sense of smell is also supposed to side in the sensitive tentacles, often found at the entrance of the outh and respiratory apparatus, beyond which no special organ for is sense has yet been discovered in those animals.

In some of the Annulosa, as in the Crustacea, the habits of the imal (as of the lobster, for example, which enters the lobster-pot in ep water, probably attracted by the smell of the bait) justify the ference, that they possess an olfactory sense; but, by what part or gan, unless by the smaller antennæ, this is exercised, is unknown. ıe open cavity in the base of these antennæ, which admits the water its interior, may be, as Rosenthal thought, the organ of smell. In e Insects, as in the carrion-flies and others, there is also reason to fer the existence of a very perfect sense of smell; for they are racted by putrid meat, some of them even depositing their ova in ınts possessing that odour. Bees are possibly attracted to very stant clover-fields, or other feeding grounds, by means of an olfactory ıse. In the Insecta, it is also conjectured that the antennæ are the ıelling organs. Dugès found that, after the removal of the antennæ, sects did not manifest their usual cognisance of the vicinity of smells. ssibly the palpi may also be concerned in the exercise of this sense. the necrophorous beetles, a curious double, cushion-like structure ists in a cavity in the broad upper lip, which is well situated for an gan of smell. Many insects suffer irritation from fumes or vapours tering their respiratory tubes or trachea; but there is no reason to nsider such sensations as allied to true smell. In certain of the olluscoida and Annuloida, ciliated recesses, or disc-like spots, situated the head, may serve as olfactory organs; but in many of them, as ll as in the Cœlenterata and Protozoa, the existence of smell is ubtful, and certainly no special organ of that sense, is known.

THE SENSE OF HEARING.

The Organs of Hearing.

The auditory apparatus is usually described as consisting of three parts; the *external* ear, fig. 74, *b*, *m*; the *middle* ear, or *tympanum*, *t*; and the *internal* ear, or *labyrinth*, *s*, *c*.

The external ear consists of the *pinna* or *auricle*, and the *external auditory meatus*, or *canal*. The pinna, the part usually

Fig. 74.

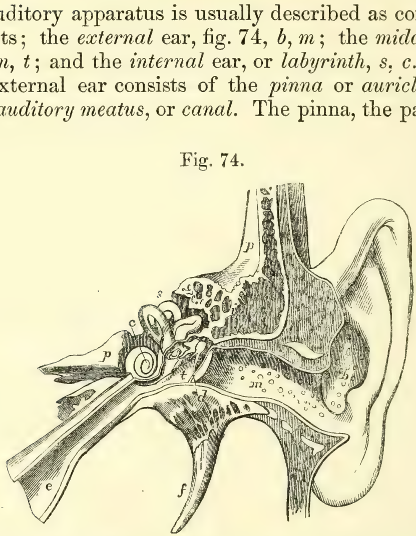


Fig. 74. Diagram, showing the parts of the external, middle, and internal ear, in connection with each other. *b*, concha of the auricle. *m*, half section of the external auditory meatus, with its ceruminous glands; it leads from the concha to the membrana tympani. *d*, is one half of this membrane, or the membrane of the drum of the ear, which divides the external from the middle ear. *t*, the cavity of the tympanum, or drum of the ear, containing three little ossicles; it is also called the middle ear. *e*, the Eustachian tube, which leads from the tympanum to the back of the pharynx. *i*, the mastoid cells, which also communicate with the tympanic cavity. *s*, the semi-circular canals. *c*, the spiral walls of the cochlea; these two last-named parts, with the vestibule, form the internal ear or labyrinth; they are lodged and encased in the petrous portion of the temporal bone, *p*, *p*. *f*, the styloid process.

called the ear, fig. 74, presents an outer border or rim called the *helix*; a curved ridge, internal to this, is the *antihelix*; within the antihelix, is the principal fossa, called the *concha* (a shell), *b*, which leads directly into the external auditory meatus, *m*. In front of the concha, and overlapping the meatus

a small pointed eminence, generally studded with hairs on s inner and concave surface, called the *tragus*; opposite to iat, is another eminence, the *antitragus*, and below this, is the *bule.* The framework of the auricle is composed of a firm astic cartilage, having nearly the same shape and varieties of ırface, as the perfect auricle, but it does not extend into the bule. It is connected with the neighbouring parts by ligaients, and is provided with three feeble muscles, named the tollens, attrahens, and retrahens auris. The skin covering ie auricle, contains sebaceous glands; these are most numerous ı the concha. The external auditory meatus, *m*, is a slightly ırved tube, extending, from the concha, inwards to a memranous partition, named the *membrana tympani*, *d*, which comletely closes it at the bottom; it measures about $1\frac{1}{4}$ inch in ngth, and is narrowest in the middle part. The outer half the meatus has cartilaginous, and the inner half bony, walls; ie former is continuous with the cartilage of the auricle. he skin lining the meatus, is very thin, especially towards ie bottom of the canal, where it is prolonged over the memrane of the tympanum, forming its outer layer; in the ırtilaginous part, it is provided with fine hairs, sebaceous ands, and numerous ceruminous glands; the latter secrete ie *cerumen* or *ear-wax.*

The middle ear, or *tympanum*, *t*, is a small cavity, or chamer, in the temporal bone, containing air, and certain small ones, named the *ossicles* of the ear, and a few muscles and erves; it is placed between the membrana tympani and the uter wall of the labyrinth. Its outer boundary is formed by ie *membrana tympani*, *d*; this is a thin semi-transparent memrane, of an oval shape, which slopes from above, downwards ıd inwards, and from behind, forwards and inwards, and is xed by its circumference, to a slight groove in the bone. It the resemblance of this membrane to the head of a *drum*, iat has given the name of *drum* of the ear, or tympanum, to ie middle ear. This membrane is composed of three layers; ı outer one, which is an extension of the skin lining the exrnal meatus, an inner layer, similarly derived from the ıucous membrane lining the tympanum, and an intermediate yer, consisting of fibrous and elastic tissue, in which are blood essels and nerves: the middle layer is said to consist of two ıminæ, the outer of which, is composed of radiating, and the ıner of annular fibres. (Toynbee.) The inner wall of the ympanic cavity, corresponds with the outer surface of the

labyrinth. The tympanum communicates, behind and above, with cells in the mastoid process of the temporal bone, called the *mastoid cells*, *i*; in front and below, it opens into the *Eustachian tube*, *e*, a trumpet-shaped canal, partly osseous, partly cartilaginous, leading into the upper part of the pharynx. There are also several small apertures, for the passage of vessels, nerves, and minute muscles.

The little bones or *ossicles* of the ear, the smallest in the body, are three in number; they are stretched across the tympanic cavity, from the membrana tympani to the inner wall of that chamber, fig. 74, and are named the *malleus*, the *incus*, and the *stapes*. The *malleus*, fig. 75 *a*, 76 *a*, or *hammer-*

Fig. 75.

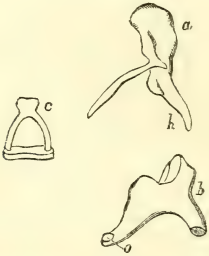


Fig. 75. The three ossicles of the ear, found in the cavity of the tympanum (magnified) (Arnold). *a*, malleus, or hammer, its head; *h*, handle of the malleus; the other process is the processus gracilis. *b*, the incus, or anvil, consisting of a body and two processes, to the longer one of which, or long leg, is affixed the tubercle or orbicular bone, *o*. *c*, the stapes or stirrup bone, consisting of head, bars, and foot-piece or base.

like bone, is attached, by a somewhat twisted process, called its *handle*, *h*, to the inner surface of the membrana tympani, near its centre; this attachment of the bone, causes the membrane to be drawn in, as it were, towards the tympanum. Another long and very delicate process, called the *processus gracilis* descends to the floor of the tympanum; whilst its rounded part or *head*, which is also somewhat fixed to the roof of that cavity, is articulated with a concave surface, figs. 75, 76, on the thick part of the incus. The *incus*, or *anvil-like* bone, *b* consists of a massive part or body, and of two processes or legs, being shaped somewhat like a double tooth. Besides being articulated with the malleus, the incus is attached, by its

shorter leg, to the hinder wall of the tympanum; by its long leg, it is articulated with the third ossicle or stapes, which is the innermost of the three bones, by a little tubercle named the *orbicular* bone, *o*, which is sometimes regarded as a separate bone. The *stapes*, figs. 75, 76, *c*, so named from its remarkable resemblance to a stirrup, is placed horizontally, and is attached, by its foot-piece or base, to the inner wall of the

Fig. 76.

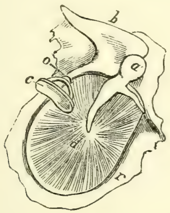


Fig. 76. The membrana tympani, seen from the inner side, with the ossicles of the ear attached. *d*, the membrana tympani, set in the tympanic ring, *r*, of the temporal bone. *a*, the malleus, its long process or handle attached to the inner side of the membrana tympani, its slender process fixed in a recess in the wall of the tympanum, its head connected with the next ossicle. *b*, the second ossicle, or incus, its body joined with the malleus, its short leg standing out towards the side of the tympanum, and its long leg reaching to the third ossicle, to which it is fixed by a little tubercle, *o*, sometimes named the orbicular bone. *c*, the third ossicle or stapes, placed horizontally, with its base, in the natural condition, turned in the direction of the inner wall of the tympanum.

tympanum, where it is fixed, by fibrous membrane, to the margin of an oval aperture in the bone, called the *fenestra ovalis*, leading into the labyrinth; it is so attached, as to be able to undergo certain movements. The foot-hole in this diminutive stirrup, is closed by a membrane, in its perfect state. These little bones, which weigh only a few grains, are covered with periosteum, supplied with blood vessels, articulated together by perfect moveable joints, and provided with minute muscles, which, acting on the small levers formed by this jointed rod, influence the condition of the membrana tympani on the one hand, and of the fibrous membrane uniting the base of the stapes to the margin of the fenestra

ovalis, on the other. The conjoined bones rotate upon a horizontal axis, passing through the slender process of the malleus, the head of that bone, and the body and short process of the incus.

The *muscles of the tympanum* are, like the bones, three in number. Two of these, the *tensor tympani*, and the so-called *laxator tympani*, arise from definite points of the surrounding petrous bone, and are inserted into the malleus; the first named, is undoubtedly muscular, and draws the membrana tympani inwards, and tightens it; the latter was formerly described as a muscle having the opposite action, but it is either seldom present, or, as maintained by some authorities, is merely a reddish ligamentous structure. The tensor tympani muscle, according to Toynbee, is enclosed in a tubular ligament, which, he supposed, keeps the tympanum in a state of medium tension, the tensor tympani only being called into play when the tension of the membrane is increased. When the tensor tympani acts, the head of the long leg of the incus is drawn inwards, so that the base of the stapes, which is articulated with it, must also advance towards the inner wall of the tympanum, and so press in the membrane of the fenestra ovalis. Fick has proved this, by direct observation. The third muscle, called the *stapedius*, is inserted into the stapes; it is generally regarded as a tensor of the membrane of the fenestra ovalis, but, by some, it has been described as relaxing that membrane. It is the smallest muscle in the body. The tensor tympani is supplied by a nerve from the otic ganglion, the laxator, it is said, by the chorda tympani nerve, and the stapedius by a branch of the facial nerve.

Below and rather behind the fenestra ovalis, on the inner wall of the tympanum, is another small rounded opening in the bone, called the *fenestra rotunda*; it is closed in the recent state, by a membrane.

The mucous membrane lining the tympanum, is thin, and, for the most part, covered with ciliated epithelium; it assists in closing the two fenestræ, and serves to form the inner layer of the membrana tympani. In the latter situation, it is said to be destitute of cilia; lastly, it is reflected over the little ossicles, and the tendons of their muscles, and also over the chorda tympani nerve, which traverses the tympanum. It contains no mucous glands, but is constantly moistened with a yellowish fluid. In front, it is continuous with the ciliated mucous membrane lining the Eustachian tube, and, through it,

with that of the upper part of the pharynx: behind, it enters, and lines, the mastoid cells.

The *internal ear*, or *labyrinth*, fig. 74, *s*, *c*, and fig. 77, so-called from its complicated communications, contains the essential parts of the organ of hearing, viz., the membranous labyrinth and the cochlea. It consists of certain complex chambers and canals, each enclosing membranous and fluid contents; it is buried in the substance of the petrous portion

Fig. 77.

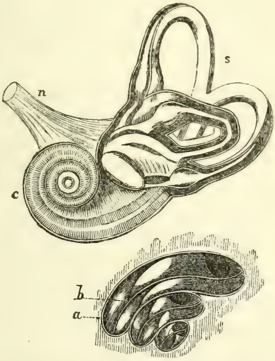


Fig. 77. Plan of the labyrinth or internal ear, showing its cavity laid open; enlarged. *n*, the auditory nerve, entering the labyrinth from the cavity of the cranium. *s*, the bony semicircular canals, laid open, showing the membranous canals within them, and their ampullæ or enlargements; also the membranous vestibule and saccule, lying in the central portion of the osseous labyrinth named the vestibule. Leading from this, is the spiral coil of the cochlea, *c*, also laid open, so as to show the striated surface of its lamina spiralis.

The lower figure shows a section through the cochlea, from base to apex. *a*, is the bony wall of the spiral tube, and *b*, the spiral partition, which divides each spire into two canals, named the scalæ, the upper one here being, throughout, the scala tympani, and the lower one, the scala vestibuli. (Arnold.)

of the temporal bone, and communicates, but by closed apertures, externally, with the middle ear, through the fenestra ovalis and fenestra rotunda, and internally, with the internal auditory meatus, which transmits the auditory nerve. The labyrinth consists of three parts, named, respectively, the *vestibule*, the *semi-circular canals*, *s*, and the *cochlea*, *c*.

The *vestibule*, see fig. 77, the central chamber of the bony labyrinth, is of an oval shape, corresponds in position with the fenestra ovalis and the base of the stapes, and communicates freely with the semi-circular canals and the cochlea. It is the fundamental portion of the labyrinth, and is the only part present in the lowest Vertebrata.

The *semi-circular canals*, *s*, are placed above and behind the vestibule ; they are three in number, and are designated, according to their position, *vertical*, *horizontal*, and *oblique*. These canals are curved bony tubes, about $\frac{1}{20}$th of an inch in diameter, each having, at one end, a dilated part, twice as wide, called the *ampulla*. As two of these tubes join together at one end, the three communicate with the vestibule, by five openings.

The *cochlea*, figs. 74, 77, *c*, is a little spiral canal, with bony walls, resembling a small snail's shell, whence its name; it is placed in front of the vestibule, forming the anterior part of the labyrinth, and measures, from base to apex, about $\frac{1}{4}$th of an inch. It possesses a bony axis, called the *modiolus*, formed, as it were, by the coalescence of its spiral turns. A thin spiral bony plate, the *lamina spiralis*, projects from the sides of the modiolus; this plate, which turns round the modiolus, like the thread of a gimlet, gives attachment, in the recent state, to a double membrane, which contains some remarkable structures, to be presently described, and which is extended across to the outer wall of the spiral canal, fig. 77, *a*. The partly bony and partly membranous spiral plate, *b*, which gradually narrows from the base to the apex of the cochlea, divides the turns of this canal, internally, into two semi-cylindrical spiral canals, named the *scalæ*. One of these, at the base of the cochlea, opens freely into the vestibule, and hence is named the *vestibular scala*. The other, the *tympanic scala*, ends at the fenestra rotunda of the tympanum. The two scalæ, moreover, *communicate*, at the summit, or *cupola*, of the cochlea, by an opening in the membranous part of the spiral septum, named the *helicotrema*.

Within the vestibule and semi-circular canals, are certain membranous *sacs* and *canals*, which constitute what is named the *membranous labyrinth*. In the vestibule, are two sacs, a smaller one, globular in form, the *saccule*, lying near the entrance into the cochlea, and a larger one, of an oblong form, called the *common sinus* or *utricle*, placed near the openings of the semi-circular canals. In the interior of the semi-circular

canals, are three *membranous semi-circular canals*; they are of the same form as the bony canals in which they are enclosed, having their respective ampullæ, and opening into the utricle by five orifices.

The walls of the membranous labyrinth, are firm and semi-transparent: they consist of three layers; the outer one is a loose vascular structure, containing pigment cells; the inner one consists of polygonal epithelial cells; the intermediate layer is a thick glassy-looking fibrous tunic. The saccule, utricle, and membranous canals, contain a limpid, slightly albuminous fluid, called the *endolymph*. Within the walls of the saccule and utricle, are two roundish clusters of solid imperfectly crystalline particles of mixed carbonate and phosphate of lime, called *otoliths* or *otoconia*, that is, *ear-stones* or *ear-sand*; the otoliths are connected with the fine ends of the vestibular branch of the auditory nerve, to be presently described. In the membranous canals and ampullæ, a few scattered particles of the same calcareous matter, are also found. The otoconia, or ear-sand, is wanting in some persons.

The interval between the inner walls of the osseous labyrinth and its membranous sacs and semi-circular canals, as well as the scalæ of the cochlea, in which there are no membranous sacs or canals, is occupied by a thin, slightly albuminous fluid, called the *perilymph* or *liquor Cotunnii*; it resembles in composition, the endolymph just named, and is secreted by a delicate fibro-serous membrane, which lines all the inner surface of the osseous labyrinth; it supports the sacs, the canals, and the nerves distributed to these parts.

The cochlea, moreover, presents certain peculiar microscopic structures, upon and within the membranous portion of its spiral partition. Thus, the bony part of the lamina spiralis, presents a grooved margin, the upper edge of which, viz. that corresponding with the scala vestibuli, supports a finely toothed membrane, named the *zona denticulata*; its lower edge being perforated for the passage of nerves, is called the *habenula perforata*. These margins of the lamina spiralis, moreover, give attachment, each to a fine layer of periosteum, the upper one of which, connected with the zona denticulata, and turned towards the vestibular scala, is named the *membrane of Corti*; the lower one, seen in the tympanic scala, is called the *basilar membrane*. These two membranes form the semi-transparent partition, formerly known as the membranous part of the lamina spiralis. Between these two layers, is a triangular

space, smaller than either of the scalæ, and now named the *scala media* (Kölliker), which is the essential auditory portion of the cochlea, and probably contains fluid. In the scala media, are found two sets of minute rod-like bodies, arranged parallel with each other, in a radiated position from the axis of the cochlea, named the *rods of Corti*; the rods of the two sets, are inclined towards each other above, so as to form an angle, where they appear to be connected together by a fine membrane, the *membrana velamentosa*; when viewed from the surface of the membrane, the series of rods suggests a resemblance to the keys of a piano. Between the grooved margin of the lamina spiralis, and the first set of the *rods* of Corti, is a cavity, and between the second set and the external wall of the cochlea, is another cavity, each containing nucleated cells of large size, named the *cells of Claudius.* The zona denticulata becomes gradually narrower, from the base to the summit of the cochlea; and so, in fact, must, more or less, all the structures of the membranous part of the spiral lamina. The outer margin of the membranous part of the spiral partition of the cochlea, has been described by some, as being composed of involuntary muscular fibres, and has received the name of the cochlear muscle. But this is not generally admitted; its structure being regarded as of the nature of delicate periosteum.

The *auditory* or *acoustic* nerve, the portio mollis, or soft portion of the seventh cranial nerve (p. 315), is the special nerve for the sense of hearing. In the petrous portion of the temporal bone within the cranium, is a short canal or passage, known as the *internal auditory meatus*, the bottom of which corresponds with the vestibule and the base of the cochlea, and is perforated by numerous small openings, whence it is named the cribriform plate. The auditory nerve, fig. 77 *n*, enters this meatus, and there divides into two branches, named the cochlear and vestibular nerves, the funiculi of which pass through the minute openings in the bottom of the meatus, into the labyrinth. The nerves destined for the saccule, utricle, and membranous semi-circular canals, are gathered into five or six bundles, invested and supported by the lining membrane of the cavity. Two of these bundles pierce the walls of the saccule and utricle, at the situations of the otolithes; here the fibres spread out, some radiating on the inner surface of the walls of the cavities, others lying amongst the earthy particles, and ending in free points. The remainder of these bundles are

distributed to the ampullæ of the membranous semi-circular canals, within which they end in a manner not yet understood, certain fine hair-like processes, here visible, being possibly the ends of the nerves, or else a fine hair-like epithelium. The numerous filaments of the cochlear nerve, ascend along small canals running up the modiolus; they then diverge laterally, in regular succession, along other little channels formed in the bony part of the lamina spiralis, on the under surface of the margin of which, that is, in the tympanic scala, they form a plexus, which contains ganglionic nerve cells. The branches from this plexus, pass through the habenula perforata of the bony lamina spiralis, to reach the scala media. The ultimate fine and free extremities of these nerves, are said, by Kölliker, to end in the fluid of the scala media, where they probably become connected with the rods of Corti; some are also supposed to pass amongst, or into, the cells of Claudius.

Sound and its Propagation.

Sound, as sound, has no existence in nature, and, indeed, cannot exist independently of a sense of hearing. When sound is generated, certain disturbances of state in elastic bodies occur, as the result of concussion, friction, or other evidences of force; these disturbances have been proved to be delicate undulations, capable of regular propagation in all directions. The presence of some *matter* to be thrown into vibration, is indispensable; for sounds can neither be produced in, nor propagated through, a vacuum.

Sonorous vibrations may originate in solid, liquid, or aëriform, bodies. Their propagation to the ear, may take place through either of these media. The rate at which sound travels in air, is about 1,050 feet per second. In water, it travels about 4 times, and in highly elastic solid bodies, from 7 to 18 times as rapidly as in air. Sounds are transmitted most readily, from solids to solids. In passing from solids to water, they undergo a certain loss, and from solids to air, a much greater loss. From water to solids, they pass easily; but from water to air, and from air to water, with very great difficulty. In their passage from air to solids, they undergo very considerable loss in their intensity. It will thus be seen, that the principal impediments to transmission, occur, in the passage of vibrations to and from solids and air, and to and from water and air; but by the interposition of certain pecu-

liar arrangements of solid materials, in the form of elastic membranes, these impediments are almost entirely overcome; for a tense and dry membrane is easily made to vibrate, by sonorous undulations in air, and can, in return, readily excite them in air; moist membranes, on the other hand, scarcely vibrate under these circumstances. A tense membrane, however, placed between water and air, facilitates very considerably, the passage of sonorous undulations in either direction. The transmission of the sound waves, in both cases, is rendered easier, when some perfectly solid body is combined with the membrane, though still it is less easy than the transmission of sonorous undulations from water to solids, or from solids to water. The physical action of such membranes, is of great importance in reference to the passage of sonorous vibrations through the acoustic apparatus of the ear. Membranes, whether tight or loose, conduct sounds in water, without loss. In their passage from solids to water, sonorous undulations seem to reinforce the undulations in the water itself; this is more particularly the case, in the vicinity of the solids.

In being propagated through the air or other medium, sounds lose their intensity, according to the distance through which they travel. From their source, they are propagated equally in all directions; and therefore, like light, they diminish in force or intensity, according to the square of the distance. Thus, sounds heard at 2, 3, or 4 times a certain distance, are diminished in intensity in the ratio of 4, 9, or 16.

When atmospheric sound waves meet with the surface of any opposing body, they are in part returned or *reflected* from it; the angle at which the reflection takes place, is equal to the angle at which the sound waves strike the surface, *i.e.*, the angle of reflection is equal to the angle of incidence. The reflection is sometimes almost entirely complete, as happens when the opposing body is fixed, solid, and very rigid. Sounds are reflected in water, as well as in air. Some of the atmospheric sound waves, instead of undergoing reflection, communicate to, or excite in, the opposing body, according to its elasticity or susceptibility, vibrations similar to their own.

The *communication* of sounds, merely consists in the conveyance of sonorous vibrations from one body to another; such communication is common to both noises and definite tones. The *excitation* of sound by one body in another, is a different phenomenon, and occurs, in its purest forms, only with regular or definite tones. It is essential for this, that the natural note.

emitted by the exciting and excited body, when struck or sounded, be identical. If two strings, *e.g.*, tuned to the same note, be placed side by side, and one be made to vibrate, the other is, at once, thrown into corresponding undulations, and gives forth the same note; this is called the *reciprocation* of sounds; the bodies are called *reciprocating*, and the sounds *reciprocal*. In the same manner, dry stretched membranes reciprocate their corresponding or natural notes. When a sounding body, instead of exciting its own fundamental note, in another body or in parts of it, excites other notes bearing certain harmonious relations to it, the latter body is said to *resound*, and is called a *resonant* body. This form of excitation of sound is not so pure as the one previously mentioned. The air itself is, in this sense, both a reciprocating and resonant body, more particularly when it is isolated in tubes, or is confined in closed chambers.

It has been stated by Helmholz, that although certain sounds consist merely of a fundamental note, produced by a single set of uniform vibrations, yet that most sounds are caused by combinations of the fundamental note, with certain secondary or harmonic notes; and that the timbre or quality of sounds, is dependent on the manner in which these secondary sounds are associated together in groups, named, by Helmholz, *sound colours*.

Those sound waves, the number of undulations of which corresponds or bears a certain definite numerical proportion to each other, are more or less agreeable to the ear, and are named *concords*; those which do not, are disagreeable, when heard together, or in succession, and are called *discords*.

Hearing.

In Man and air-breathing animals, sounds excited in the atmosphere, reach the fluid of the labyrinth by two paths—first, through the mixed membranous and osseous tympanic apparatus; and, secondly, through the cranial bones. The passage of such sounds through the tympanum, is effected readily, and with great range and delicacy of appreciation. Through the solid bones of the head, however, the transmission of sounds excited in the atmosphere, is accomplished with difficulty; were it not so, the noises which would thus be produced, would be unbearable, and they would, moreover, confuse the sounds received through the tympanum. It is

through the bones of the head, that sounds are transmitted t the internal ear, when, from any cause, the tympanum ceas to conduct sound. In speaking and singing, the hand place on the head, distinctly feels the vibrations of the cranial bone and the auditory nerve is excited by them, when the ears a closed.

Certain sounds produced by the concussion of solids again solids, reach the fluid of the labyrinth directly through th cranial bones; *e.g.*, the note of a tuning fork, held against th teeth or sides of the head, gives rise to sonorous vibration which are much more powerful than when transmitted t the ear through the air, and which can even be heard aft its first sound has ceased to be distinguishable through the ai It is in this manner, that sonorous vibrations are trans mitted to the ear, when this is placed on the ground, and it also of importance in hearing one's own voice. When the ea are closed, the sound of our voice transmitted through th cranial bones, is powerful, but its tone is altered. The tickin of a watch, heard when placed between the teeth, and the nois produced by striking the teeth together, are further exampl of sounds conveyed through the cranial bones. The bones the head also conduct sounds, when these are transmitted to through water, as in the case of divers. When the head submerged, and the ears are closed, the noise produced by th knocking together of two stones in the water, is very distinctl heard.

Such sounds as are produced by atmospheric undulations sufficient power to affect the cranial walls, as, *e.g.*, the repo of artillery and the sound of thunder, are transmitted to th internal ear, partly in a direct manner, by the cranial bone partly by the tympanum; for, though the ear be tightl closed, such sounds are still audible. The external ear i however, the proper inlet for almost all air-borne sonorou vibrations, and the tympanum is their proper path to th labyrinth. The particular use fulfilled by each part of th complex auditory apparatus, in the conduction of sound wave to the nerve of hearing, may now be considered.

The *pinna*, or *auricle*, from its varied form, must receive, an partly reflect, the atmospheric sound waves from and in man directions. Most of these undulations must be reflected ex ternally; but the size of the auricle, its position, and externa projection from the head, the direction of its general con cavity, which is turned somewhat forwards, its dense, firm

structure, the tightness and smoothness of the skin investing it, and lastly, the form of the concha, and the relation of that recess to the external auditory canal, clearly indicate its office of collecting sound. The sonorous waves collected by the concha, are reflected from it, so as to impinge upon the inner surface of the tragus, and are again reflected from the latter into the meatus. The auricle, moreover, conducts a certain number of sonorous undulations through its cartilaginous walls; this, perhaps, affords some explanation of the various and singular disposition of its surfaces, of its eminences and depressions, which are probably intended to meet the slighter sound-waves in such opposite and conflicting directions, as to enable them to neutralise each other, so that those which are properly conveyed to the membrana tympani through the air of the meatus, may not be confused. This view is favoured by the fact, that the cartilage of the auricle has only one narrow point of connection with that of the meatus, and that it is cut up by many fissures, which partially separate its different portions. Some, however, suppose that the inequalities presented by the auricle, are intended to receive at right angles, and therefore favourably for complete conduction, sonorous undulations from all directions.

The *external auditory meatus* receives and conducts sonorous vibrations to the membrana tympani. The impairment or loss of the power of hearing sounds which come through the air, caused by stopping the meatus with the finger, or by obstructing it with water, cotton-wool, or other substances, indicates its function as a conductor of sound. Owing to the curved direction of the canal, and to the partial concealment of its outer end, it is impossible for the atmospheric sound waves to pass straight down from the exterior to the membrana tympani; they must undergo reflection many times, and at various angles, chiefly from the internal surface of the concha and of the tragus, down into the meatus, and from all sides of the latter, through the air within it, on to the tympanic membrane. The walls of the meatus, like those of the auricle, also conduct sounds; but their conducting power for atmospheric sound waves, is but feeble, and, in the ordinary condition, is probably specially provided against. If the meatus be closed externally, with the tip of the finger, and the auricle or tragus be scratched, or if a watch be held against these parts, the sounds produced are extremely loud. Through resonance, the sounds, in fact, appear to be of increased intensity; for, the

closed meatus constituting a resonant chamber, the resounding vibrations, excited in the air contained within it, act on the membrane of the tympanum, and, in this way, intensify the original sound. It is in a similar manner, that those sounds which pass through the teeth, or cranial bones, and which are known as head-sounds, are also rendered very much louder. The resonance of the mass of air contained within the meatus, also gives increased strength to the intensity of atmospheric sounds. If, indeed, a tube be added to the meatus, so as to lengthen the auditory passage, the intensity of all sounds becomes much greater.

The *membrana tympani* is admirably adapted for the reception of atmospheric sound waves, and, although it may, to a certain extent, be thrown into vibrations through the osseous ring in which it is set, it is principally intended to be acted upon by the atmospheric undulations received through the auditory meatus. Its area is equal to about $\frac{1}{12}$ of a square inch. The slanting position of the membrane at the bottom of this canal, not only serves to increase its area, but is probably intended to adapt it for the reception of more numerous vibrations from the walls of the meatus, it may be, at some given angle, or in a perpendicular direction. In its usual condition, the membrane is in a state of moderate tension, due partly to its own structure, and partly to the support afforded it by the long process of the malleus. For a wide range of notes, its state of tension must be constantly undergoing variations; thus, for low sounds, it must be relaxed; for high sounds, it must be rendered tense. If, *e.g.*, we close the mouth and nostrils, and force air into the tympanum, through the Eustachian tube, by means of an expiratory effort, or if we exhaust the air in the tympanic cavity, by an inspiratory effort, we increase the tension of the tympanic membrane; in this state, grave sounds are rendered less audible, or become altogether inaudible, whereas high ones are heard with greater distinctness.

The vibrations produced in the membrana tympani, are propagated chiefly, most readily, and, indeed, in a concentrated manner, through the tympanic *ossicles*, to the fluid of the labyrinth. The undulations of this membrane are communicated directly to the handle of the malleus, whence they pass to the head of this bone, are then propagated to the incus and stapes, and from the base of the latter bone, which, as already mentioned, is fixed by membrane into the fenestra ovalis, to the

perilymph of the labyrinth. In performing this office, the chain of ossicles transmits the sonorous vibrations, communicated to them as a whole, and not vibrations resulting from motions in their particles. The direction of the undulations is unaffected by the angular arrangement of the ossicles; for the undulations are propagated, as they would be through a series of levers, from the stapes to the fenestra ovalis, in the same direction as that in which they are communicated to the handle of the malleus, viz., in a perpendicular direction. It has been maintained by some, that the ossicles are merely employed as levers to regulate the tension of the three membranes of the tympanic cavity, *i.e.*, of the membrana tympani, of the membrane which, with the base of the stapes, closes the fenestra ovalis, and also through the medium of the perilymph in the cochlea, of the membrane closing the fenestra rotunda. The ossicles are, according to this view, not conductors of sonorous vibrations, which, it is supposed, are propagated solely through the air in the tympanic cavity, either to the membrane closing the fenestra rotunda, or else to the inner wall of the tympanum generally, and, in this manner, to the parts within the labyrinth. Sounds conducted through two such different paths as the ossicles and air of the tympanum, must interfere with, and confuse, each other, and hence it is probable, that they are conducted solely, either through the one or the other path. Considering the special connection of the ossicles with the expanded membrana tympani on the one hand, and with the chief aperture of the labyrinth on the other, their almost complete isolation in the atmosphere of the tympanum, and their greater conducting power, as compared with that of air, we must conclude that the little chain of ossicles is the actual path for the conveyance of sounds. In the tympanic cavity, on the contrary, we find contrivances apparently intended to impair the conducting power of the air within it; for this cavity communicates freely with the Eustachian tube and the mastoid cells; the inner surfaces of all these parts, are moist, so that sonorous undulations, in whatever manner they may be excited within them, must be damped and deadened; moreover, the tympanic ossicles being invested by moist mucous tissue, are very bad conductors of vibrations to, or from, the air within the tympanum; so that, in this manner, they are secured against loss in one way, and interference in another. Again, the mucous lining of the tympanum, is also especially adverse to the propagation of vibrations

from the walls of the cavity, to the tympanic atmosphere, a well as to the reception of any such as, striking on its inne surface, might, if received upon a dry membrane, interfer with those which impinge upon its external boundary, t membrana tympani. Lastly, the fenestra rotunda, the sup posed path of the vibrations propagated through the air in th tympanum, is, in comparison with the fenestra ovalis, smal retired in position, and has but a limited connection with th cavities of the labyrinth; in many animals endowed wit a highly acute auditory sense, it is even placed in a neighbou ing cavity, which communicates with the tympanum through very narrow fissure. It will thus be seen that, whilst th tympanic apparatus presents a combination of membranous an solid materials, well adapted for the conduction of sonorou vibrations, the tympanic cavity seems to possess contrivanc specially calculated to impair the conducting properties of i contained air.

The membrana tympani is, moreover, a defensive structur preventing the entry of foreign bodies into the tympanum by it also the interior of this cavity is kept in a state moisture. The interposition of the tympanic cavity, betwe the outer and inner parts of the ear, serves, by the maint nance of warm air, at a uniform temperature, in that situatio to preserve the delicate structures of the labyrinth from ex posure and changes of temperature, conditions essential f the performance of their functions.

By means of the *Eustachian tube*, which leads into th upper part of the pharynx, equal atmospheric pressure on th two sides of the membrana tympani, is maintained; the fre dom of movement of the membrane, both in vibrating and changing its degree of tension, is secured, and its und tension, which would arise if either of its sides were subjecte to excessive or deficient pressure, is prevented. Moreove the existence of this outlet, protects the membrana tympa against the effects of external atmospheric shocks, and preven accidental rupture or laceration. The Eustachian tube al serves as a conduit for the escape of the fluids secreted in th tympanum and mastoid cells; this is aided by the cilia cove ing its interior. The pharyngeal ends of those tubes, are on open in swallowing and yawning; they can, moreover, opened at will, by closing the mouth and nose, and then forcin air into them, or by performing the act of deglutition, when clicking noise is heard, from the motion of the tympanic mem

brane and ossicles. The Eustachian tube is, however, always pervious in the healthy condition, and this is essential for the due performance of its functions; for when it is obstructed by accumulation of the fluids secreted by the parts, by the pressure of enlarged tonsils, by swelling of the mucous membrane at its orifice, or by any other cause, deafness, in proportion to the amount of obstruction, is produced. It was formerly supposed, that these tubes conduct one's own voice to the ears; this notion is, however, erroneous; the ticking of a watch introduced into the mouth, is but feebly heard; moreover, obstruction of the tubes does not render the hearing of one's own voice more difficult than that of other sounds.

The state of tension of the membrana tympani, is regulated by the action of the muscles connected with the malleus and stapes. There can be no doubt, that when the tensor tympani contracts, this membrane is drawn inwards, and that its tension is thereby increased. The action of the stapedius on the membrana tympani is doubtful; some regard it as also a tensor, but others as a laxator, of this membrane. But these two muscles must also influence the condition of the membrane which, with the base of the stapes, closes the foramen ovale. By Fick, the tensor tympani, acting indirectly on the stapes, is said to press inwards that bone; if so, it must tighten the membrane of the foramen ovale, and so increase the pressure, through the contents of the labyrinth, on the membrane of the fenestra rotunda of the cochlea. Concerning the action of the stapedius on this membrane, there is still, however, considerable doubt: some suppose that it must aid the tensor tympani in tightening, not only the membrana tympani, but also that of the foramen ovale; whilst others have conjectured, that it not only relaxes the membrane of the drum, but also draws outwards that of the oval foramen, and so diminishes the pressure, through the contents of the labyrinth, on the membrane of the fenestra rotunda.

In all the Vertebrate, and also in the aquatic non-Vertebrate animals, the sonorous undulations traverse a *fluid* medium, before they impinge on the extremities of the auditory nerve. In Man, and in the air-breathing Vertebrata, the undulations propagated from the tympanum, pass through the perilymph of the labyrinth, partly to the membranous utricle, saccule, and semi-circular canals, so as to reach the nervous filaments contained in their interior, and partly along the scala vestibuli of the cochlea, pulsating over its denticulate zone, rods of

Corti, and radiating nerves, up to its very summit, and thence, down the scala tympani, to the membrane of the fenestra rotunda. The exact use of the fenestra rotunda, and of the membrane closing it, is not well understood. As already mentioned, it has even been supposed by some, to receive vibrations directly from the air in the tympanum. But if, in hearing, the sonorous vibrations pass through the ossicles to the labyrinth, this membrane of the fenestra rotunda, may either act as a spring, protecting the structures of the cochlea from too strong or sharp undulations, or it may prevent the return of those undulations backwards, along the scalæ of the cochlea. The weakness of the tympanic muscles, and the elasticity of the membranes which close in the labyrinth, are opposed to the idea, often entertained, of the occurrence of any great variation in the degree of tension of the fluid contents of the labyrinth. The changes above described, are mainly effected through the increased, or diminished, pressure of the base of the stapes at the fenestra ovalis.

On the supposition that the tensor tympani and stapedius muscles *tighten* both the membrana tympani, and the membranes of the foramen ovale and fenestra rotunda, and necessarily also the joints of the chain of ossicles between them, they must serve to protect the auditory nerve from too powerful vibrations, and, at the same time, render the auditory apparatus better adapted for the reception of high tones, and less fitted for the reception of low notes. These offices are probably regulated by reflex nervous action, and so may be compared with the functions of the iris, in regard to the regulation by it, of the quantity of light which is admitted into the eye to act on the retina. But, on the supposition that the tensor tympani tightens both the membrane of the drum and the two membranes of the labyrinth, whilst the stapedius relaxes those three membranes, their reciprocal, but opposed, actions may be compared to those of the circular and radiating fibres of the iris, the former of which narrow, whilst the latter widen, the pupil, or aperture through which the light enters the eye. It is interesting to note, that these two little muscles of the ear are, like the circular and radiating fibres of the iris, supplied, the one by a cranial motor nerve, viz., the facial, and the other by a sympathetic branch, viz., from the otic ganglion, the two sets of the fibres of the iris being supplied, the former by the third pair, the latter by branches from the ophthalmic ganglion of the sympathetic.

Concerning the functions performed by the various parts of the *labyrinth*, nothing is positively known. The *fluid* contained in its chambers, serves to support the various membranes and nervous structures within it, in a certain degree of tension; and it is, as already stated, the last medium by which the sonorous vibrations are finally conveyed to the auditory nerve, the material particles of which must also be thrown into corresponding mechanical vibrations.

The *vestibule* is the part essential to the simplest exercise of the sense of hearing; for, even in the most rudimentary conditions, both of the human ear, and of that of the lowest Vertebrata, the vestibule, or the central chamber of the labyrinth, is the part first developed in connection with the recipient extremities of the auditory nerve. It is, in the lowest Fishes, the only part of the labyrinth which is present. Moreover, so long as it remains unimpaired, the sense of hearing in Man and the higher Vertebrata, is not lost, although all the external and tympanic portions of the ear be destroyed. From its position opposite to the base of the stapes, it must first receive the sonorous vibrations travelling by that path, and may serve to transmit them to the rest of the labyrinth.

The *cochlea* and its nerves, must undoubtedly receive direct vibrations, *i.e.*, vibrations communicated through the bones of the cranium; for there exists an intimate connection between the lamina spiralis, on which the nerve tubules are distributed, and the osseous walls of the labyrinth, the two being continuous with each other. But the nerves distributed to the membranous part of the lamina spiralis of the cochlea, must also receive sonorous vibrations transmitted from the tympanic apparatus, either by the fenestra ovalis, or the fenestra rotunda, through the fluid of the cochlea and its special recipient and translating apparatus, which converts the mechanical into the nervous sonorous vibrations. It has been conjectured, that the lamina spiralis, with its highly complex, denticulate, rod-like, and nervous structures, is, on account of the graduated lengths of some, at least, of its component parts, connected with the reception of sounds of different *pitch*, the sonorous undulations of which are themselves of various lengths. The rods of Corti especially, have been supposed to act like vibrating elastic bars of different lengths, just as different-sized tuning-forks vibrate in unison only with their own note, or with its harmonics. Another conjecture may be offered, namely, that in the complex apparatus of the cochlea, there may also exist contrivances

for arresting the vibrations, after they have accomplished the due stimulation of the auditory nerve, in the same manner as the dampers of a piano stop the vibrations of the strings, so as to prevent the confusion of successive notes, thus performing, as it were, an office corresponding with that of the choroid coat in the eye, which absorbs the rays of light after they have acted on the retina, and thus prevents the confusion of successive images. The idea that the cochlea is an organ for distinguishing pitch, was suggested by Dugès, and considered by him, to be supported by the general concurrence of the development of the cochlea with the relative extent of the vocal sounds, in the same class of animals, as may be understood, by comparing the cochlea and the voice in Mammalia, Birds, and Reptiles. Helmholz further attributes to the graduated structures of the lamina spiralis of the cochlea, the office of receiving the impressions which produce the so-called *sound colours* already referred to, and so of aiding in the recognition, not only of the pitch, but of the *timbre* or quality of sounds. Each nervous filament is supposed to receive single vibrations ; and the combinations of these in harmonic groups, with the fundamental notes, in the production of ordinary sounds, are recognised, with greater or less facility, by different persons. There are individuals as unable to appreciate musical sounds, as others are to distinguish colours; whilst persons possessed of an acute musical ear, may be compared with those who are remarkable as colourists. Supposing that the cochlea may be the part, through which we receive impressions concerning pitch and timbre, and so of melody and harmony, the membranous labyrinth may be the part which informs us of the intensity, quality, or loudness of sounds.

The *semi-circular* canals, or rather, their contained membranous canals, assist in the reception of sounds from the cranial walls. They are also supposed to be specially concerned in distinguishing the *direction* of sounds. The relative position of these canals favours this idea ; for in Man, and in almost all animals in which they exist, they occupy three planes nearly at right angles with each other, and therefore corresponding with the three dimensions of a cube.

The *otoliths*, or otoconia, when present, are supposed to intensify the sonorous undulations, at, or near, the fine extremities of the auditory nerves of the vestibule, saccule, and ampullæ of the semi-circular canals.

The sense of hearing varies much, as regards acuteness, in

different persons; so also does the power of distinguishing differences in pitch. The power of judging of the direction of sounds, would seem to be almost wholly the result of habit. The different intensity of a given sound, as heard by the two ears, may assist in the determination of a knowledge of its direction; but, to a certain extent, one ear will suffice for this purpose. The notion of the distance of sounding bodies, is also acquired by habit, the mind chiefly judging from the relative loudness or faintness of a known kind of sound; but, in this respect, there is great liability to deception, and hearing is not so accurate a guide as sight. Like the other senses, hearing can be much improved by education; in the blind, it is so highly developed, that they are mainly, if not entirely, guided by it, in walking. The Indian, by listening on the ground, can detect the distant foot-fall of his enemy or prey.

The auditory nerves can be excited by various internal mechanical causes, operating generally through certain movements of the blood and blood-vessels; for example, in dilatation of the vessels from congestion of the head, in extravasation of blood, in morbid conditions of the circulation in the brain and internal ear, dependent on extreme debility, in narcotic poisoning, and in great bodily collapse, as before the commencement of fainting. Obstructions in the tympanum, or Eustachian tube, may also produce abnormal noises in the head. It is not yet determined whether electricity can excite the auditory sense, unless indirectly, by disturbance of the tympanic apparatus.

Sonorous undulations conducted through the tympanum, are referred, by the sensorium, to the exterior; whereas those conducted through the cranial bones, appear to proceed from the head itself.

As in the other organs of sense, here also, there are after-sensations and subjective sensations. For example, the noises in the ear, which remain after certain sounds, when these have excited the auditory nerve for a lengthened period, are analogous with the after-sensations of touch, taste, and smell. The noises in the head and ear, such as musical phrases, and the singing, buzzing, ticking, and humming sounds, heard by persons suffering from disease of the brain or auditory nerve, are examples of subjective sensations. Delusions of the auditory sense are not uncommon, especially amongst excitable persons.

The various uses of the sense of hearing are sufficiently obvious.

The Organs and Sense of Hearing in Animals.

The organ of Hearing, in Mammalia generally, is, in all particulars, constructed on the same plan as that of Man. The external ear consists of a cartilaginous pinna, and of a partly cartilaginous and partly osseous meatus. The former is often large, and provided with numerous powerful muscles; in the beaver, otter, and other diving animals, it is but slightly developed; in the seals, the mole, the Cetacea, the armadillo, and the ornithorhynchus, it is absent. The external meatus is sometimes provided with a fold of the auricle, by means of which it can be closed, as the ear-flap of the elephant, and the valve-like antitragus of the water-shrew. The general development of the external ear, appears to be proportional to the acuteness of hearing. It attains its highest development in the bats, in which its forms are often remarkable. The entrance to the tympanum is usually surrounded by a separate bone, the os tympanicum; but in the monkey, as in man, this is blended with the petrous part of the temporal bone. The cavity of the tympanum frequently extends widely into the adjacent osseous structures. The tympanic ossicles are three in number; they present great variety of shape, although they always resemble those of man. In some marsupials, the stapes is simply style-shaped, with a broad base, or is divided into two short crura only, a condition which somewhat approaches the representative bone, the columella, in birds. In the Cetacea, the walls of the tympanum are very thick, and, when detached from the rest of the petrous bone, form the remarkable so-called ear-bone of those animals; in them, the Eustachian tube is membranous. In different species of Mammalia, the cochlea forms from $1\frac{1}{2}$ to 5 turns. The labyrinth is completely embedded in the petrous portion of the temporal bone; in the mole, however, the vertical semi-circular canals project into the cavity of the skull. In some Mammalia, no otoliths, nor even otoconia, are present.

In Birds, the external meatus is present; there is, however, no pinna, but only a radiated arrangement of the feathers, or a few flaps of skin around the aperture; these are very large in the owl tribe. Otherwise, the organ of hearing is highly developed. The membrana tympani is oval, and projects externally, instead of sinking inwards, as in Mammalia. The tympanum communicates with the mouth, by a very large Eustachian tube, and also, by different foramina, with air cells in the cranial bones; these cells are very capacious, and generally even extend across the middle line, so that the two tympanic cavities are connected with each other. There is only one tympanic bone, a modified stapes, here named the columella, which is joined, by two or three cartilaginous processes, representing the other bones, to the membrana tympani, and rests, by its other extremity, upon the foramen ovale. The tensor tympani is the only muscle present. The three semicircular canals are of large size, in proportion to the cranium; the vestibule is small. The cochlea is not convoluted, but forms a slightly curved conical canal; in its interior, are two slightly twisted cartilaginous folds, which represent the spiral lamina of the Mammalia.

Reptiles generally, are unprovided with an external ear, the crocodile alone possessing a rudimentary pinna, in the form of two folds of skin, the upper one of which encloses a plate of cartilage, and possesses a

muscular valve. All reptiles, except serpents, possess a membrana tympani, tympanic cavity, and Eustachian tube. In the serpents, however, these parts are absent, and the columella, which is represented by a small rod-like bone, is embedded in the flesh. In some, the membrana tympani is visible externally, in others, it is covered by the skin. The columella consists of a row of little bones; the first, corresponding to the stapes, closes in the fenestra ovalis; the second represents the incus, and the third, a cartilaginous portion connected with the membrana tympani, the malleus. The labyrinth contains a rudimentary cochlea, consisting of a short, conical, straight, or slightly curved canal, divided, by an internal septum, into two scalæ. This simple form of cochlea illustrates very well the formation and structure of the more complex spiral cochlea in the Mammalia and Man; for by imagining such a double conical tube or canal to be rolled upon a central axis, the shell-like organ of the higher Vertebrata would be produced. There are three semi-circular canals provided with ampullæ. The sac of the vestibule contains otoliths, which form a friable mass.

In Amphibia, the cochlea is absent, and there is no fenestra rotunda. Some possess a tympanum, others do not. The triton has merely a vestibule with a single otolith and three semi-circular canals; the vestibule approaches the exterior by the fenestra ovalis, which is not occupied by the stapes, but is closed by a small lid. The flat plate of the stapes, alone represents the auditory ossicles; it lies in the muscles. In the fully developed frogs, with but few exceptions, there is a membrana tympani, and a tympanum, from which a short Eustachian tube passes into the throat. The pipa has a cartilaginous membrana tympani, and its two Eustachian tubes open, by a common orifice, in the middle of the palate. The walls of the labyrinth are partly cartilaginous, partly bony, and this cavity ends externally in the fenestra ovalis, from which three ossicles, in part cartilaginous, pass across the tympanum, to the membrana tympani.

In Fishes generally, the external ear and tympanum never exist. The cochlea also is absent, so that even the internal ear is incomplete. Some osseous fishes, however, present rudiments of a tympanic cavity. The vestibule always contains a utricle, and generally a saccule as well, each with its included otolith; connected with these, are either some imperfectly developed semi-circular canals, or one, two, or, more commonly, three perfect canals of large size, ending in the vestibule. In certain cartilaginous fishes, viz. the rays and skates, the cavity of the vestibule is prolonged to the surface of the back part of the head, where a membrane, which may be said to correspond with that closing the fenestra ovalis, is seen. The walls of the vestibule and semicircular canals, which are either cartilaginous or bony, according to the character of the skeleton, usually project into the cranial cavity; in the higher forms only, are they partly contained in the temporal bone. No auditory organ has yet been discovered in the amphioxus.

From the preceding account, it will be seen, that a fully developed spiral cochlea exists only in the Mammalia; that this part is comparatively simple and slightly curved in Birds, is quite rudimentary in Reptiles, or altogether absent, as in the aquatic chelonia, and is wanting in Amphibia and Fishes. The tympanic chamber and apparatus, together with the Eustachian tube, are also simplified in Birds and Reptiles, below

which a tympanum does not exist, except in the most highly develop amphibia, in which a small tympanum is present, but there is no fenest rotunda. The above-named structures, including also the fenestra ova and fenestra rotunda, are therefore proper to animals which live entire *in air*. This general fact must be regarded as a proof of the speci office of these parts, as conductors of atmospheric sounds. In tho which inhabit water exclusively, the semicircular canals and vestibu alone are present, and even the former disappear in the lowest organis fishes, leaving the vestibule only as the representative of the audito organ. In such cases, the sonorous vibrations must reach the labyrin directly, through the framework of the head. The otoliths are mo largely developed in the simpler forms of auditory apparatus.

In such of the non-vertebrated animals as are purely aquatic, t auditory apparatus consists essentially of a sac or vestibule, in which more or less regularly formed cretaceous otolith is found, and which connected with a special nerve. Into this sac, the sonorous undulatio are readily conveyed from the water; it is analogous to the me branous vestibule of the vertebrate ear. In the air-breathing Annulo other contrivances, of which dry elastic membranes, calculated to recei vibrations through the air, form a part, are met with.

In the Mollusca, double symmetrical organs of hearing are present all the classes, even in certain Lamellibranchiata. They are co nected, by means of short auditory nerves, either with the subœsophage ganglia, as in the higher Mollusca, or with the pedal ganglia, as in t Gasteropodous and lower forms. In the Cephalopoda, these orga consist of two flask-shaped *sacs*, the analogues of the membran labyrinth of the Vertebrata. They lie close together, in an excavation the cartilage of the head, the cartilaginous vestibule. Each contains a la cretaceous otolith, with some fluid. The space between the sac and t cavity in which it is lodged, is filled with gelatinous fluid, and the cav itself is perforated by the auditory nerve, which is distributed to t sac. In the remaining classes of the Mollusca, the organs of heari are more simple, each consisting of a simple roundish or oval s situated in the soft parts, closely attached to the auditory nerve, a containing a fluid, with a central otolith suspended in it; sometim the sac is lined with a ciliated epithelium. Amongst the Molluscoi similar auditory vesicles are found in some Ascidioida.

The Annulosa are not universally provided with acoustic organs. Insects, it has been conjectured, that such organs exist at the base the antennæ, where a soft membrane, made tense by those parts, supposed to represent a sort of tympanic membrane; others imagi that the antennæ themselves, being supplied with large nerves, c appreciate vibrations. In the grasshopper and cricket tribes, there sometimes found, on both sides of the first abdominal ring, a large oblo depression, set in a firm horny ring, and closed at the bottom by a de cate membrane. A little vesicle, containing a watery fluid, is connect with the inner surface of this membrane, by means of two horny pr cesses; this may be regarded as a sort of rudimentary labyrinth. T auditory nerve, which proceeds from the third thoracic ganglion, form swelling as it spreads over the vesicle, which is, by some, regarded mere as a portion of the nerve. A large tracheal sac, near the auditory s connected with the third stigma, may perform the office of a tympanu

In certain locusts, the organ of hearing is still more curiously placed, viz. on the chief segment of the front limbs: it consists also of a vibrating or tympanic membrane, sometimes superficial, sometimes embedded in a cavity, having a slit-like aperture; near it, is found a tracheal chamber, and the nerve spreads out upon it, in the form of fine parallel striæ. In the Myriapoda, organs of hearing have not yet been found. The Arachnida appear to possess considerable auditory sense, but no special organ of hearing has been discovered in them. Amongst the larger Crustacea, the organ of hearing is now said to be usually situated in the basal joint of the first pair of antennæ. In this situation, for example, in the lobster and river crawfish, there exists a hollow chamber opening externally by a narrow slit in its thin membranous walls, and occupied by a sac filled with water, in which are frequently found minute particles of sand, which have entered from without. On one side of this chamber, is a fine striated structure; a nerve, which arises, with the nerve of the antennæ, from the sub-œsophageal ganglion, spreads out upon it. A greenish glandular mass, found near this sac, is analogous to the cement gland in the cirrhopods, which are, however, destitute of auditory sacs. The acoustic function of this antennal sac has been doubted, because its small tympanum-like covering membrane seems less adapted to convey vibrations, than the firm shell of the animal; moreover, since in some species, it exhibits an opening which permits of the entrance of water into its interior, it has been described as an olfactory organ. (Rosenthal.) This organ presents great varieties among the decapoda; in the spiny crab, its covering is crustaceous, and little muscular bundles are found beneath it. In the squilla, it is altogether wanting; but in them, in certain species, there is found, in the base of the second and seventh thoracic pairs of feet, and, in mysis, in the inner pair of the tail-plates, a completely *closed* sac, containing a spherical crystalline body, provided with stiff bristles, which has been regarded as an auditory organ, analogous, in its formation, with the simple auditory vesicles of the lower Mollusca. In the Annelida or worms, a pair of ciliated auditory vesicles, with contained otoliths, is often present in the head; they are connected with the œsophageal ring. The great variability in the seat of the auditory apparatus, is accordingly quite as marked in the Annulosa as in the Mollusca, as is exemplified especially in the grasshopper, locust, mysis, and squilla, in which, as in the Gasteropodous and Lamellibranchiate Mollusca, it is associated with the pedal or locomotive ganglia, or even with some part of the locomotive apparatus. In the Vertebrata, likewise, the organs of hearing are connected with the back of the medulla oblongata, lower than the centres of origin of the nerves of the other special senses, and nearer, therefore, to the motor apparatus generally.

Amongst certain of the Annuloida, as in the marine Turbellaria, and perhaps also in some Rotifera, an auditory vesicle, containing an otolith, and no longer double and symmetrical, but single, is found lying closely on the chief nervous ganglion. But most of the Rotifera, and all the Entozoa, are destitute of special auditory organs; nor has any such apparatus been detected in the Echinodermata.

In the Cœlenterata, however, there are found, in both the discoid and ctenophorous forms, but chiefly in the medusæ, auditory sacs named *lithocysts*, which enclose crystalline particles, supposed to be analogous

to otoliths; these are numerous, and are found on the margin o the disc; they frequently have pigment spots, or ocular spots, nea them.

The Protozoa are entirely destitute of auditory organs.

THE SENSE OF SIGHT.

The Organs of Sight.

The *organs of sight*, in Man, consist of the *eyeballs* or *globe* of the *eyes*. The external protective *appendages of the eye* are the *eyebrows*, the *eyelids*, and the *lachrymal gland* and *ap paratus*. The eyeballs and the lachrymal glands, are lodge in the bony cavities, named the *orbits*.

The *orbits* are pyramidal in shape; their apices are directe backwards and inwards, so that their axes converge posteriorly and diverge anteriorly. In the apex of each orbit, are severa openings, which transmit the optic nerve, the common sensory motor, and sympathetic, nerves of the eyeball, as well as it bloodvessels and lymphatics. The orbit also contains th lachrymal gland, the *ocular muscles*, and a quantity of fat, o which the eyeball rests and moves as upon a soft cushion between this and the eyeball, is a loose cellular capsule.

The *eyebrows*, or the arched eminences surmounting th orbits, consist of thick musculo-cutaneous ridges, enclosin some fat, and studded with hairs set obliquely outwards.

The *eyelids*, or *palpebræ*, are the two thin movable *cover* of the eyeball, the free margins of which are bevelled, an beset with the *eyelashes*. The upper one is larger and mor movable than the lower one, and is provided with a specia muscle, named the *levator palpebræ*. Each eyelid consist of a thin semilunar plate of soft fibro-cartilage, the *tarsa cartilage*, which gives it form and support; outside this car tilage, is a thin, delicate, and very loose skin, destitute of fat and a few pale striated muscular fibres, belonging to the so called *orbicularis* muscle, together with some non-striate muscular fibres, which are more numerous in the lower li (H. Müller); on its inner surface, it is lined with mucou membrane. The cartilage of the upper lid, is larger an thicker than that of the lower lid, which forms merely a nar row plate. The cartilages are connected, at their orbital o attached margins, with the periosteum of the circumferenc of the orbit, by broad membranes called the *fibrous mem branes* of the lids. At the outer angles, these membranes ar

strengthened, and tie the outer ends of the cartilages to the bone; the inner ends of the cartilages are connected with a short, strong, horizontal tendon, called the *tendon of the eyelids*, or *tendo oculi*, which extends from the tips of the cartilages, to the inner wall of the orbit. The cartilages are kept in contact with the eyeball, in all its various movements, by means of a small muscle, named the *tensor tarsi*, placed behind the tendon of the eyelids.

The *levator palpebræ* muscle, above mentioned, arises from the bottom of the orbit, and passes forwards above the eyeball, to be inserted into the posterior edge and surface of the upper tarsal cartilage; it pulls back this lid, and so uncovers the front of the eyeball. The lower lid has no depressor muscle to lower it, but descends a little by its own elasticity. According to Wagner, the unstriped muscular fibres of the lids, also co-operate in opening the eyelids, being governed, as shown by experiment, by the sympathetic nerve. The ordinary closure of the eyelids, is accomplished by the action of the part of the orbicularis muscle which lies upon the eyelids; their more forcible closure, by the part of the same muscle which surrounds the orbit. The levator palpebræ muscle is supplied by the third cranial nerve, and the orbicular muscle by the seventh or facial nerve.

The mucous membrane lining the inner surface of the eyelids, is continuous with the skin at the free margins of the lids; it is reflected from the lids, over the fore-part of the eyeball, so as to connect these two parts, whence it is called the *conjunctiva*; it is also prolonged into various ducts and canals. Where it covers the anterior transparent part of the eye, named the cornea, the conjunctiva is very thin, colourless, and but slightly endowed with sensibility; the part covering the white portion of the eyeball, called the sclerotic coat, is somewhat thicker. On the inner surface of the eyelids, it is much thicker, highly vascular, very sensitive, provided with closely-set papillæ, and firmly adherent to the cartilages. It is covered by a many-layered squamous epithelium.

On the ocular surface of the tarsal cartilages, between them and the conjunctiva, are situated the *Meibomian glands*. These are modified, and complex, sebaceous glands (fig. 78), consisting of a series of ducts, placed side by side, and perpendicularly to the margins of the lids, each communicating with numerous lateral follicles or crypts, *b*. They occupy little grooves on the inner surfaces of the cartilages, and their ducts

open, by minute orifices, *a*, on the free margins of the lid
Each duct, with its lateral crypts, resembling rows of onio
on a string, consists of a membranous wall, lined with a gla

Fig. 78.

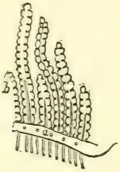


Fig. 78. A portion of the margin of the upper eyelid, showing a few of the Meibomian glands attached to it. *a*. orifices of the central ducts of each gland. *b*, rows of follicles or sacs, arranged upon each central duct.

dular epithelium, which secretes a sebaceous matter. In th
upper lid, there are about thirty glands; in the lower li
from fifteen to twenty, and they are much shorter.

The elliptical interval between the opened eyelids, is calle
the *palpebral fissure*; the outer and inner angles of this fissur
are named the *canthi*. At the outer canthus, the bevelled ma
gins of the lids, form an acute angle; but at the inner canthu
the margins, which are here rounded, are separated by
small interval, called the *lacus lachrymalis*, the *lachrymal lak*
or *pit*, fig. 79. Along the margins of the eyelids, are tw
or more rows of finely-curved hairs, named the *cilia* or *eye*
lashes; in the upper lid, they are more numerous, thicker, an
longer than in the lower lid; the lashes of the upper lid curv
upwards, those of the lower lid downwards, so that they d
not interlace when they meet or separate. At the inner can
thus, is placed a soft red fleshy-looking eminence, the *caruncl*
from *caro*, flesh; it is made up of a cluster of follicle
covered with mucous membrane, and studded with a few ver
fine hairs. Between the caruncle and the eyeball, is a thi
semilunar fold of the mucous membrane, the concavity o
which is turned towards the eye (fig. 79); this is the rudimen
of the *membrana nictitans* (from nicto, to wink), or *haw*, o
the horse and mammalia generally, and of the *third eyelid* o
birds. In front of the edge of this membrane, on the margi
of each eyelid, are two little conical eminences, named th
lachrymal papillæ; in the apex of each of these, is a smal

aperture, the *lachrymal punctum.* These puncta are the commencement of the lachrymal canals, which carry away the secretion of the lachrymal glands.

The *lachrymal gland* in each orbit, is a small almond-shaped body, figs. 79, 1, fig. 80, *g*, situated in a slight depression at the upper and outer part of the orbit, between it and the eyeball; it reaches forwards to the upper eyelid, with which a portion of it is connected. This is a compound racemose gland, and its ducts, from six to twelve in number, open on

Fig. 79.

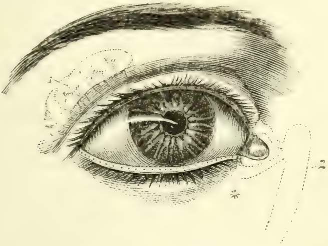


Fig. 79. Front of the eyeball and its appendages. 1, dotted outline, showing the position, size, and shape of the lachrymal gland. 2, similar outline, showing the form and position of the lachrymal sac and nasal duct. On the left hand of this, other dotted lines indicate the course of the two lachrymal canaliculi, leading into the sac, one above, and one below, the lachrymal lake or sinus, which is occupied by the caruncle; between the caruncle and the eyeball, is the edge of the rudimentary nictitating membrane. The asterisk * indicates the orifice of the lower canaliculus, named the inferior lachrymal punctum. The orifices of the Meibomian glands, are seen in the margin of the lower eyelid. The white exposed part of the eyeball, corresponds with a portion of the sclerotic coat of the eye. The circular dark-coloured part represents the iris, perforated by the pupil, and covered by the transparent coat or cornea.

the inner surface of the upper eyelid, just above the outer canthus. The tears are a clear, saline, alkaline fluid, and contain a minute quantity of albuminoid matter; their total solid constituents amount to only 1 per cent.

The *lachrymal canals*, or *canaliculi*, fig. 79, commence, as already stated, at the lachrymal puncta; they are two short tubes, placed beneath the skin, one above, and one below, the lachrymal lake; the superior canal, which is smaller and longer than the lower one, passes upwards and then inwards

the inferior downwards and then inwards, and both terminat in a large membranous bag, called the lachrymal sac.

The *lachrymal sac*, 2, is lodged in the deep lachryma *groove*, formed in the inner wall of the orbit; it terminate below, in a narrower tube, the *nasal duct*, which extends to the inferior meatus of the nose. The lower end of the nasal duct, is somewhat expanded, and is often partially closed by a membranous fold or valve.

The lachrymal sac and canals consist of fibrous and elastic walls, lined internally by mucous membrane. The epithelium of the mucous membrane, in the canals and upper part of the sac, is laminated, squamous, and destitute of cilia; in the lower part of the sac, and in the nasal duct, it is ciliated. This membrane is continuous above, through the canaliculi, with the conjunctiva, and below, through the nasal duct, with the pituitary membrane lining the nose.

The eyebrows, by their elevation and depression, influence the amount of light reaching the eyes; they also serve slightly to protect these organs from foreign bodies, and from the perspiration running down the forehead.

The eyelids, eyelashes, and lachrymal apparatus, are parts admirably adapted for the preservation and protection of the eyes. By means of the two former, the entry of foreign bodies floating about in the air, is prevented, and the eyes are protected from excessive light. The eyelids, besides, play a most important part in cleansing and moistening the surface of the eyeball. In the act of winking, which may be voluntary, but is usually reflex, and consists merely in the rapid shutting and somewhat slower re-opening of the lids, foreign bodies are carried inwards, by a kind of sweeping movement to the lachrymal lake. The secretions of the conjunctiva and glandular appendages of the eye, when flowing in moderate quantity, partly evaporate, but are chiefly conveyed towards the lachrymal puncta, whence the residuary fluid portion passes partly by capillary attraction, and partly by the action of the orbicularis muscle, and of the tensor tarsi muscle, hence called the *muscle of the lachrymal sac*, into the lachrymal canals and sac, and thence, through the nasal duct, into the nose. Deep and quick inspirations may likewise aid the descent of the fluid, by an exhausting or sucking action. When the secretion of the lachrymal glands is greater in quantity than can be carried away by the lachrymal ducts the overflow constitutes the tears.

The secretions of the lachrymal gland and conjunctiva, moisten the surface of the eye, facilitate the movements of the eyeball, and, preventing loss by evaporation, preserve the transparency of the so-called cornea. The tears are the most abundant of these secretions; but after the loss of the lachrymal gland, the eye still remains moist. The sebaceous secretion of the Meibomian follicles, lubricates the margins of the eyelids, prevents their adhesion, and protects them from the action of the tears. An increased flow of tears is excited by the action of strong light, by irritants operating on the conjunctival, nasal, and lingual branches of the fifth cranial nerve, by vomiting, violent coughing, and by mental emotions causing laughing or crying.

The Eyeball.

The *eyeball*, or *globe of the eye*, fig. 80, is a strong closed membranous sac, rudely compared to a globe, but in reality composed of a large segment of one sphere, having a small segment of a lesser sphere affixed to it prominently in front, *c*. The diameter of these two spheres is about as 11 to 7. The eyeball is furnished with a number of small muscles, which closely surround it, and is abundantly supplied with vessels, lymphatics, and nerves. It is attached behind, to the optic nerve *n*, and is also maintained in position by its muscles, which pass to it from the orbital walls. In front, the eyeball is free. It measures about one inch in its antero-posterior diameter, and about one line more, from side to side. The coats of the eyeball are partly *transparent*, partly *opaque*, the former occupying a portion of the front of the eyeball, the latter the remainder of the globe. The former constitutes the *cornea*; the latter, of which only a part is visible, is the white coat, named the *sclerotic*. Within this coat, is spread out a black *pigmentary* layer, named the *choroid*, and within this, the *retina*, the delicate nervous expansion of the optic nerve. The interior of the globe is partially divided into two parts by a perforated septum, named the *iris*, and is occupied by certain transparent media, called *humours*. The rays of light penetrate the transparent coat and media, to reach the back part and sides of the interior of the eyeball; passing through the opening in the iris, and impinging on the retina, they form upon it, definite images of external objects. The effects of such impressions are conveyed by the optic nerve to the sensorium, and excite the sensation of light.

A straight line passing directly backwards, through the centre of the cornea, or transparent part of the eyeball, is named its *antero-posterior*, *visual*, or *optic*, *axis*. This does not correspond with the axis of the orbit, which passes obliquely backwards and inwards. The antero-posterior axes of the two eyeballs, are *parallel*, when the eyes are at rest, and

Fig. 80.

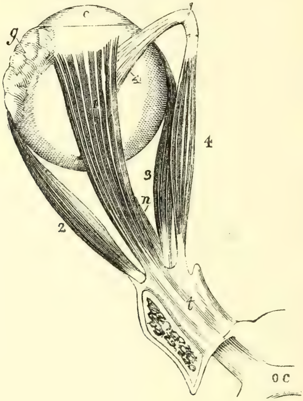


Fig. 80. Left eyeball, seen from above, with a portion of the bone at the bottom of the orbit, the left optic nerve, and the optic commissure, showing some of the ocular muscles. 1, superior rectus muscle. 2, external rectus muscle. 3, internal rectus muscle. 4, 4, superior oblique muscle, passing through the trochlea or pulley, by which the direction of its tendon is changed, before it is inserted into the eyeball. *t*, common tendinous origin of the ocular muscles, surrounding the optic foramen, at the bottom of the orbit. *g*, the lachrymal gland. *c*, the transparent coat of the eyeball, or cornea. The rest of the eyeball is covered by the sclerotic. *o c*, the optic commissure. *n*, the left optic nerve passing obliquely forwards, in the axis of the orbit, to reach the eyeball. The antero-posterior axis of the eyeball, when at rest, is not oblique, but is directed forwards, the axes of the two eyeballs being then parallel.

also in certain motions. The *optic tracts*, on each side, arise from the optic thalami and corpora quadrigemina, and may be regarded as prolongations of the cerebrum, rather than as nerves; they converge, and join in the middle line, to form the *optic commissure*, *o c*, from which, in front, the optic nerves are given off. These nerves diverge to enter the optic

foramina, *t*, of the orbits, where they receive a protecting sheath from the dura mater, processes from which, pass between the nervous funiculi. Each nerve, after entering the orbit, pierces the sclerotic and choroid coats of the eyeball, about $\frac{1}{10}$th of an inch to the nasal side of, and a little below, its antero-posterior axis, and then expands into the retina.

The *muscles* which move the eyeball are six in number. Of these, four are called straight, and two oblique. The *straight*, or *recti*, muscles are named, respectively, the *superior*, 1, *inferior*, *external*, 2, and *internal*, 3, *rectus*. They arise from the borders of the optic foramen, where they surround the optic nerve, and pass forward, to be inserted respectively into the upper, lower, outer, and inner sides of the eyeball, on its opaque, or so-called sclerotic coat. The oblique muscles are named, the one *superior*, the other *inferior*. The superior oblique, 4, 4, arises, like the recti muscles, from the border of the optic foramen, and passes forward to the upper and inner side of the orbit; there, it ends in a small tendon, which runs through a fibro-cartilaginous *pulley*, or trochlea, attached to the bone in this situation, and lined by a synovial membrane; hence this muscle has received the name of the trochlear muscle. From the pulley, the tendon of the superior oblique muscle is reflected backwards and outwards, to be inserted into the sclerotic coat, on the upper surface of the eyeball, a little behind its middle. The *inferior* oblique muscle arises from a depression in the inner and fore part of the floor of the orbit, passes outwards and backwards, beneath the eyeball, and is inserted into the sclerotic coat, upon the outer and posterior surface of the globe.

The straight muscles are so attached, that they can turn the eyeball upwards, downwards, inwards, or outwards, according to the muscle brought into play; hence they have been named respectively, the *attollens*, *depressor*, *adductor*, and *abductor* muscles of the eyeball. If two adjoining recti muscles act together, the eyeball is carried in an intermediate or oblique direction. When all four muscles act simultaneously, the eyeball must be strained backwards, and some have supposed that by this action, the antero-posterior diameter of the eyeball may be increased. When in a state of rest, the elasticity of the surrounding structures, keeps the eyeballs in their parallel position, and this parallelism is accurately maintained in many of its movements. But if one muscle becomes weaker than its antagonist muscle, or obtains an undue preponderance

over it, the natural position of equilibrium is destroyed, and the distortion named *strabismus* or *squint*, either internal, or external, for example, is produced. The oblique muscles rotate the eye on its antero-posterior axis, the superior oblique rolling its upper half inwards, the inferior oblique rolling its lower half inwards. These two muscles, being inserted *behind the transverse axis* of the eyeball, also turn its anterior surface outwards and downwards, when the superior oblique acts alone, and outwards and upwards, when the inferior oblique acts alone. Their combined action turns the anterior surface of the ball directly outwards.

The upward and downward movements of the eyeballs, are more rapid than those from side to side, or than the oblique movements; the motions, which are very perfectly under the control of the will, are so rapid as to be singly immeasurable, but by repeating them over several times consecutively, in each direction, the difference is multiplied, and becomes easily noticeable. All these movements are more easy of execution, if they are performed from the natural, or, as it were, instinctive position of rest of the eyeballs—that is, with the optic axes directed horizontally forwards, and in parallel lines. The primary or simple motions of the eyeballs, may be referred to rotations around three principal axes—viz., the *antero-posterior* axis, the *transverse* axis, and the *vertical* axis. The movements around the vertical axis, are performed by the external and internal recti; those around the transverse axis, by the superior and inferior recti, aided respectively, by the *inferior* and *superior* oblique muscles; the movements around the antero-posterior axis, are exceedingly slight, and are performed by aid of the oblique muscles. In these simple movements, the eyeball may practically be regarded as a sphere turning round its centre as a nearly fixed point. But besides these movements, the eyeballs are capable of executing oblique motions, as, *e.g.*, upwards and outwards, upwards and inwards, downwards and outwards, and downwards and inwards; in such movements, the eyeball moves around intermediate *secondary axes*, formed by the junctions of two others, and the movements are executed by three muscles—viz., by two of the recti with one of the oblique. Finally, with these secondary movements, and also with the primary ones, are usually combined the very slight rotatory movements of the eyeballs around their antero-posterior axes, so producing *tertiary* movements. In this way, the antero-posterior axis, and therefore,

he centre of the cornea, and the centre of the retina, may escribe either *straight* or *curved* lines over the field of vision, rom one point to another, in every conceivable way—as, for xample, when we trace the contour of a very complicated gure. Rüte's *opthalmotrope* is an instrument consisting of a novable ball, to which are fixed elastic cords in a state of light tension, representing the various muscles of the eyeball; the amount of shortening or elongation of the cords, in ny given portion of the ball, is taken to indicate the actions f the respective muscles.

The movements of the eyeball are undoubtedly voluntary, out they present certain peculiarities of very great interest. Thus, the movements of the two eyeballs are always simultaneous and definite; they are always harmonious, but very requently not symmetrical. In looking upwards or downvards, both eyeballs move harmoniously and symmetrically, he same muscles being called into play in each orbit; in ooking to the right or to the left, the eyeballs move harmoniously, but unsymmetrically, different muscles acting on the wo sides. In oblique movements to one or other side, the notions are unsymmetrical, being produced, for example, by he superior and external recti of one side, and the superior ind internal recti of the other; in rotatory movements, the ictions, though harmonious and wonderfully exact, are unsymnetrical, being executed by aid of the superior oblique of the one eye, and the inferior oblique of the other; lastly, in convergence of the two eyeballs, to look at a near object, the action s both harmonious and symmetrical, the internal recti muscles being called into play in each orbit. Again, it is to be remarked, that the movements of the eyeballs are voluntary, ind their muscles decidedly under the influence of the will, yet their motions are limited by a certain kind of *combination*, which prevents us from acting upon them in a wholly independent way on the two sides, as we can, for example, with our irms and hands. Thus, we cannot turn one eyeball up and he other down, nor both eyes outwards; nor can we depart from a certain fixed degree of convergence of the eyes, required for their accommodation to see a given object. The reason of his is, that the movements of the eyes, though voluntary, are guided indirectly by the purposes we strive to attain, which we shall hereafter see, are *single* vision with the two eyes, and exact vision. The muscles in this case, as in most others, are governed, not directly, but indirectly, by our endeavouring to

accomplish a certain end; and, as we cannot see an object singly, by directing one eye upwards and the other downwards, or both eyes outwards, we cannot accomplish those acts. If, however, the position of the image in one eye, be slowly displaced sideways, upwards, or downwards, by means of a prism, held and turned slowly before the eye, then the eyeball in question is moved, within certain limits, to one side, or up or down, so as to maintain the singleness of vision; when the prism is removed, the object is, though for a short time only, seen double. All the movements of the eyeball, excepting that of rotation around the antero-posterior axis, which is performed by the oblique muscles, may, by practice, be executed, without the exercise of vision, when the eyelids are closed, but with more or less difficulty or restraint; convergence of the eyes, as in squinting, is the most difficult to imitate. The inability to rotate the eyes by a direct volitional act, is due to the fact, that we have not learnt how to accomplish it, and not to any special structural limitation. (Helmholz.) This rotation is shown by Helmholz to be of great importance, under certain circumstances; for example, in maintaining the meridian plane of the eye in a uniform position, as to verticality, in its various secondary movements, and also in accomplishing certain special adjustments necessary for stereoscopic vision.

The eyeball is supplied with motor, sensory, and sympathetic *nerves*, derived from the third and fifth cranial nerves, and from the lenticular or ophthalmic ganglion. The so-called *ciliary nerves*, from twelve to fifteen in number, perforate the sclerotic, and are distributed to the choroid coat, to the iris, and to a muscular structure, known as the ciliary muscle. The *ciliary arteries* derived from the ophthalmic artery, are fine, of considerable length, and pursue a somewhat tortuous course before they enter the eyeball. The *veins* are fewer, but large.

The *coats* of the eyeball are the *cornea* and *sclerotic*, the *choroid* and the *retina*.

The *sclerotic* coat, fig. 83 *s*, so named from its comparative firmness, forms the outermost tunic of the larger spheroidal portion or posterior $\frac{5}{6}$ths of the eyeball, leaving an opening in front, into which is fitted the transparent structure called the cornea, corresponding with the smaller spheroidal portion, or remaining $\frac{1}{6}$th of the eyeball. The sclerotic is a strong, opaque, fibrous structure, composed essentially of white fibrous tissue,

arranged in interlaced bundles mixed with elastic tissue, and, in its deeper layers, with pigment fibres; its vascularity is not great. It is perforated behind by the optic nerve, *h*, and presents, at the place of perforation, or *lamina cribrosa*, a number of minute orifices for the passage of the nervous funiculi; in the centre of this lamina, is a larger opening, called the *optic pore*, for the transmission of the small artery which supplies the retina, the *central artery of the retina*.

The *cornea*, *c*, or the transparent convex structure, which occupies the opening in the anterior part of the sclerotic, like a sort of watch-glass set in its frame, is not quite circular, being somewhat broader transversely than from above downwards. Its convexity varies in different individuals; it is more convex in early life, and in short-sighted persons, and becomes flattened in old age. The radius of its curve is said to range from rather more than $\frac{1}{4}$th to nearly $\frac{1}{3}$rd of an inch. Like the sclerotic, the cornea is composed of fibres, but these are arranged more regularly, and are separable into closely-connected layers; its anterior and posterior surfaces are formed by specially-condensed, structureless, and highly elastic laminæ. The inner surface of the cornea forms the anterior boundary of a space within the eyeball, called the *anterior chamber*, *a*, and is lined by a single layer of flat, polygonal, epithelial cells. Its anterior surface is covered by a very fine extension of the conjunctiva, which reaches it from the fore part of the sclerotic. Where the sclerotic joins the cornea, the character and arrangement of the constituent fibres are altered, so that they form a transparent, not an opaque coat. Both these structures are supplied with nerves; but the cornea is non-vascular, and must receive its nutrient supply, indirectly, from the sclerotic and conjunctival vessels. The sclerotic is about $\frac{1}{20}$th of an inch, and the cornea about $\frac{1}{25}$th of an inch in thickness.

The *choroid* coat, *e*, is a comparatively thin, tender, vascular, black or brown, pigmentary membrane, which is perforated behind by the optic nerve, and reaches forwards as far as a circular fibro-elastic band, corresponding with the line of junction of the cornea with the sclerotic, named the *ciliary ligament*; with this, the anterior edge of the choroid coat is firmly united. The outer surface of the choroid is loosely connected with the sclerotic, by bloodvessels, nerves, and a fine cellular web, the *lamina fusca*; within this, are curious whorled veins, *venæ vorticosæ*, and numerous branching arteries, mixed with star-shaped pigment cells; within these,

is a network of exceedingly fine and close capillaries; an
lastly, the *pigmentary* layer, made up of regularly-hexagon
nucleated cells, filled with pigment granules, fig. 43, *d*. Th
choroid averages about $\frac{1}{264}$th of an inch in thickness.

The *ciliary ligament*, just mentioned, placed opposite th
junction of the sclerotic with the cornea, serves to connect thos
coats with the choroid, and also supports numerous black o
brown radiated folds or rays, called the *ciliary processes*, fig
83, *b*, which are prolongations of the fore-part of the choroi
These processes, from 60 to 80 in number, are situated in
radiated manner around the margin of the crystalline lens, t
be presently described; some of them, the larger ones, ar
about $\frac{1}{10}$th of an inch in length, and $\frac{1}{40}$th of an inch thick, be
tween which smaller ones are found. In these processes, th
capillary network is larger than in the choroid.

On the surface of the fore-part of the choroid, is a yellowish
pink band about $\frac{1}{8}$th of an inch broad, the *ciliary muscle*
this consists of involuntary muscular fibres, some having
longitudinal, others a circular direction; the former arise fro
the line of junction of the cornea and sclerotic, opposite th
ciliary ligament, and posteriorly, are inserted into the iris, th
sclerotic ciliary processes, and the anterior part of the choroi
This muscle has also been named the *tensor of the choroid*.

Fig. 81.

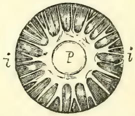


Fig. 81. The iris or perforated coloured diaphragm, removed from the eyeball. *i i*, its outer attached border. *p*, the pupillary opening in its middle.

Stretched across the interior of the eyeball, and attache
by its circumference, to the choroid, ciliary ligament, an
cornea, is the thin membranous curtain, called the *iris*, fig
83, *i*, fig. 81, *i i*, perforated a little to the inner side of it
centre by a circular opening, the *pupil*, *p*. The contractio
and dilatation of this aperture, regulate the amount of ligh
which passes into the eye. In health, the size of the pupi
varies from $\frac{1}{20}$th to $\frac{1}{3}$rd of an inch. After death, its averag
diameter is nearly $\frac{1}{4}$th of an inch. The anterior surface o

the iris, which is flat, contains pigment cells; it is brilliantly reflective, and gives the eye its special colour. The iris and pupil appear to be larger and nearer to the cornea than they really are; placing the eye under water, removes this deceptive appearance. The iris is composed of unstriped muscular fibres, a fibrous stroma, bloodvessels, nerves, and a quantity of pigment cells. The muscular fibres consist of circular and radiating fibres; the *circular* fibres, placed at the back of the iris, opposite the ring named the *annulus minor*, form a narrow band, the *sphincter pupillæ*; the *radiating* fibres pass from the circumference towards the pupil, near the margin of which they blend with the circular fibres, which here lose their parallel arrangement. The fibrous stroma is made up of delicate bundles of fibrous tissue, the greater number of which radiate towards the pupil; others are arranged in a circular manner. The bloodvessels form loops. The pigment cells in the substance of the iris are ramified, and are of a yellow or brown colour, according to the colour of the eye; on the posterior surface, the pigment cells are of a dark-brown or black hue, and consist of several layers, forming what is called the *uvea*. These cells are, as a rule, darker in children than in adults; in the former, the delicate pale blue tint of the white of the eye, is due to the sclerotic coat being very thin, so that the pigment within, can be partly seen through it; the pigment cells are also darker in dark persons, and in the swarthy races of mankind.

Within the choroid, is the *retina*, or the sensitive coat of the eyeball, fig. 83, *r*. This structure is a delicate nervous membrane formed by the expansion of the optic nerve. It is so supported as to present a concave surface to the light; it does not extend so far forward as the choroid, but ends, at a short distance from the ciliary ligament, in a jagged edge, called the *ora serrata*, from which an exceedingly fine membrane, not nervous, extends forwards to the ciliary processes. By its outer surface, the retina is slightly, though organically, connected with the choroid; its inner surface is bounded by a very delicate membrane, called the *membrana limitans*, which separates it from the so-called vitreous body. As seen during life, by the aid of a magnifying glass, the retina presents a reddish colour, due to the bloodvessels contained in it. Branches of the central artery of the retina are seen ramifying over it; and these, as well as the capillary network, are situated upon, or near, its inner surface. When examined

immediately after death, the retina is found to be of a pinkish colour, soft, and transparent; but it quickly becomes white or semi-opaque. In the centre of the back of the eyeball, *i. e.*, exactly in the antero-posterior axis of the globe, and, as we shall explain, in the line of most perfect vision, the retina presents, soon after birth, an elliptical yellowish spot about $\frac{1}{12}$th of an inch wide, called the *macula lutea*; in the middle of this *yellow spot*, the margins of which are slightly elevated, is a darker circular depression, named the *fovea centralis* (fovea, a pit). The retina being exceedingly thin in this situation, the pigment of the choroid is seen through it, and this gives rise to the deeper colour of the fovea centralis; the yellowish margin of the macula lutea, is owing to the presence of some special but delicate pigmentary matter. A little below the yellow spot, and about $\frac{1}{10}$th of an inch internal to it, is the *colliculus*, or point of entrance of the optic nerve; the central artery of the retina also passes into the eyball at the same place. The thickness of the retina gradually diminishes from behind forwards; its thickness varies from $\frac{1}{120}$th to $\frac{1}{240}$th of an inch.

Examined microscopically, the retina is found to consist essentially of three layers, which are held together by a very delicate connective tissue; it also contains blood-vessels. The *external* layer, formerly called *Jacob's membrane*, and now the *bacillary layer*, is very thin, and consists of a stratum of evenly-disposed, transparent, colourless *rods*, called *bacillæ*, intermixed with other larger bodies, named *cones*. These rods are solid and highly-refractive bodies, packed closely side by side, and, except those near the anterior part of the retina, which, at least in the frog, are disposed obliquely, are arranged, more or less nearly perpendicularly to the centre of the eyeball; under the action of water, these rods swell, undergo distortion, and show a division into an outer and inner segment; the outer segment is the more highly refractive; the inner one, which becomes curved on the application of water, is connected with a fine fibre, which passes vertically inwards, into the next or middle layer of the retina. The cones, or bulbous particles, disposed at regular intervals between the rods, present a similar structure, and the same connection with the middle retinal layer. The diameter of the rods is, on an average, $\frac{1}{13750}$th, that of the cones about $\frac{1}{3666}$th of an inch. The *middle* layer of the retina, also named the *granular* layer, consists of

two strata of granular or nucleiform bodies, which are connected, on the one hand, with the fine fibres proceeding from the rods and cones, and on the other, by fine processes, with the nervous elements belonging to the third or so-called nervous layer of the retina. Amongst these nuclear fibres, are some, forming the *radiating fibres* of H. Müller, which pass through the whole thickness of the retina, from between the rods and cones of the outer layer, to the membrana limitans, on its extreme inner surface, on which they end by slightly-expanded extremities. These radial fibres support the whole structure of the retina, passing between the nervous elements of the inner layer, and also between the capillary network. They may merely be modifications of connective tissue; but others of the *nuclear* fibres are distinctly connected with the rods and cones on the one hand, and with the proper nervous elements of the deepest layer on the other, and are themselves probably true nervous structures. The *internal*, or *nervous, layer* consists partly of the expanded fibres of the optic nerve, which pierce the bacillary and granular layers at the optic colliculus, and then spread out, to form the *retinal network*, in which the nerve fibres, losing their double outline, and retaining only their central or axial fibres, are arranged in fine meshes among the radiating fibres of Müller. The nerve-fibres are here very fine, measuring only from $\frac{1}{6000}$th to $\frac{1}{50000}$th of an inch in diameter. Between this network and the granular layer, is found a stratum of large grey ganglionic vesicles or nerve cells, with ramified offsets, similar to those found in the grey substance of the brain; hence this layer is sometimes named the *vesicular* layer. The offsets or processes of these cells, are said to be connected, on the one hand, with the nuclear fibres proceeding to the rods and cones, and on the other, with the axial fibres of the retinal expansion of the optic nerve; whilst some of the fine nerve fibres are also said to be traceable directly into certain of the nuclear fibres, and, through them, to be connected with the rods and cones. The capillary vessels chiefly lie in the neighbourhood of the layer of ganglionic vesicles.

From the intimate connection of all these complex elements of the retina, most physiologists are of opinion, that whilst some of the radiating fibres are possibly only supporting structures, others, as well as the rods and cones, are either actual nervous elements, or important appendages of the extremities of the nerves.

At the fovea centralis of the yellow spot, only certain of the retinal elements are present, viz., the cones of the columnar layer, which are here smaller and set closely together, a stratum of grey ganglionic nerve cells, and the membrana limitans. At the elevated margin of the yellow spot, the other ordinary retinal structures, which are absent in the fovea centralis, begin to appear. At the optic colliculus, the only elements present are the nerve fibres, radiating from that point.

The transparent humours of the eyeball, are the *vitreous humour*, the *crystalline lens*, and the *aqueous humour*.

The *vitreous humour*, fig. 83, *v*, so named from its glass-like transparency (vitrum, glass), occupies about the posterior $\frac{4}{5}$ths of the entire globe, and measures from before backwards, about half an inch. It is a colourless, transparent, jelly-like mass, enclosed in a clear membrane, called the *hyaloid membrane*, processes of which also traverse it. The vitreous humour consists of a specially modified connective tissue, called *jelly-like* or *mucous*, arranged in segments, like an orange. It is composed almost entirely of water, in which are some salts, and a little animal matter. Behind, and around, the vitreous humour is convex, and supports the retina; in front, it is cup-shaped, for the reception of the crystalline lens.

The *crystalline lens*, fig. 83, *l*, is a double convex, colourless, transparent, firm body, placed in front of the vitreous humour; it receives its name from its crystal-like appearance and its lenticular shape. It is enclosed in a transparent, structureless, highly elastic, and permeable membrane, called the *capsule of the lens*; between the capsule and the body of the lens, is a single layer of transparent nucleated cells; these cells, after death, imbibe moisture, and then, breaking down, form a liquid layer, the *liquor Morgagni*. The lens is chiefly supported in its place, by a transparent and highly elastic membranous structure, called the *suspensory ligament*; attached to the anterior surface of the capsule, close to the margin of the lens, this ligament is connected behind with the ciliary processes, and with the hyaloid membrane, which encloses the vitreous body; it may be traced as far back as the ora serrata of the retina. It presents on its anterior surface, a number of folds, which fit in between the rays of the ciliary processes. Around the margin of the lens, between the hyaloid membrane and the suspensory ligament, is a circular passage, called the *canal of Petit*.

The posterior surface of the lens, is embedded in the de-

ression on the forepart of the vitreous humour ; its anterior urface, which is free, is placed in contact with the iris, behind he pupil. The superficial portion of the lens is soft ; but owards the centre, it gradually becomes firmer and denser ; he central and firmest part is named the *nucleus*. The poserior surface, fig. 82 *d*, is more convex than the anterior ; the urvature of both surfaces, the anterior of which is said to be llipsoidal and the posterior paraboloidal, increases towards the ircumference ; its edges are rounded off. The lens measures ibout $\frac{1}{4}$th of an inch in its antero-posterior diameter, and about $\frac{1}{3}$rd of an inch transversely. The radius of the curve of its poserior surface is about $\frac{1}{4}$th of an inch ; that of the anterior surface varies, from somewhat more than $\frac{1}{4}$th to about $\frac{1}{5}$th of an inch. The substance of the lens is composed of concentric layers, which

Fig. 82.

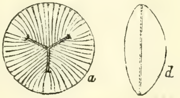


Fig. 82. Two diagrammatic views of the crystalline lens: *a*, anterior surface, showing the radiated arrangement of its component bundles of fibres, which are here seen to meet on three planes: *d*, side view, or edge of the lens. The anterior flatter surface is here turned to the left hand, and the posterior more convex surface, to the right.

are made up of microscopic parallel fibres, by some said to be tubular (Kölliker); they have uneven or indented margins, which fit together most accurately. Towards the centre of the lens, these fibres meet in certain planes, *a*, which radiate from the central axis of the lens; in the nucleus, there are three principal planes; in the superficial portion, there are as many as twelve. The lens consists of about 60 per cent. of water; the solid matter is chiefly albuminoid.

Before birth, the lens is nearly spherical, very soft, and not quite transparent, its fibres being then imperfectly developed. At this period, a small artery traverses the vitreous humour to the back of the lens ; here its branches form a plexiform network on the back of the capsule. In front of the lens, this network of vessels is met by a vascular extension from the pupillary margin of the iris, constituting the *pupillary* membrane, which then closes the pupil. By means of these vascular membranes, the humours of the eyeball are nourished during their growth.

Shortly before birth, the pupillary membrane gradually undergoes absorption, so that, at birth, almost all traces of it have disappeared. In some rare instances, however, this structure is not absorbed, but remains as a permanent part of the eyeball; in such cases, sight is necessarily interrupted.

Between the front of the crystalline lens and the posterior surface of the cornea, is a small space, measuring, from before backwards, about $\frac{1}{10}$th of an inch, and occupied by the *aqueous humour.* This interval is divided, before birth, by the pupillary membrane, into two parts, called the *anterior* and *posterior* chambers. In the fully-formed eyeball, the iris is often described as also imperfectly dividing the space occupied by the aqueous humour, into an anterior and posterior chamber; but it has been shown, that the iris rests immediately upon the anterior surface of the capsule of the lens, so that there is no posterior chamber, or interval between them. The aqueous humour consists of about five drops of a limpid fluid, resembling pure water; it contains a little salt, and a trace of animal matter. It is probably secreted by the posterior surface of the cornea, and by the vessels of the iris and of the points of the ciliary processes.

The following table shows, in decimal parts of an inch, various measurements of the eyeball and its parts (Krause):—

a. Diameters of the eyeball, through its centre:—

	Inch
Antero-posterior	·944
Vertical	·944
Horizontal	1·003

b. Thickness of the various parts in the direction of the antero-posterior axis:—

Cornea	·0393
Aqueous humour	·0984
Crystalline lens	·2755
Vitreous body	·4921
Retina and choroid	·0078
Sclerotic	·0511

c. Radii of the curves of the surfaces of the refracting media:—

Cornea	·275 to ·314
Anterior surface of lens	·275 to ·393
Posterior „ „	·236

Light.

Those bodies, such as the sun and fixed stars, from which ight directly emanates, are called self-luminous bodies. The un is the chief source of light, but there are also terrestrial ources of light, such as combustion and other chemical com-inations, friction, and electricity. Non-luminous bodies are nly rendered visible by the light which falls upon them from uminous bodies.

According to the Newtonian theory of emanation, light is f a corpuscular nature, a luminous body constantly emitting naterial particles in all directions. The undulatory theory f light, first suggested by Huyghens, and now generally dopted, supposes, that space is filled with an ether, which, vhen thrown into exceedingly rapid *undulations*, gives rise in he eye to the *sensation of light*, as the vibrations of material articles, communicated to the ear, produce the sensation of ound. In accordance with the doctrine of the correlation of orces, the undulations of light are supposed to result from ne of the modes of action of the general force of nature, nd therefore to be able to originate in mechanical, chemical, hermal, or electrical modes of action.

The undulations of the luminiferous ether being supposed to e propagated from a luminous point in *all* directions, the term *ay*, a conventional but convenient expression, is applied to ny imaginary line drawn from such a point across the waves, hat is, perpendicular to their expanding and advancing ronts. The undulations are therefore propagated in the lirection of such lines or rays; but the motions of displace-nent of the ether which produce those waves, are *transverse* o the direction of the rays.

The so-called *rays* of light *move* in straight lines; their rate f motion, in space, formerly estimated at 192,500 miles, is ow said to be about 186,300 miles per second; their velocity s retarded in dense media. Light radiates equally in all lirections, and, by spreading, its luminous power diminishes s the square of the distance through which it passes. When t falls upon any surface, it may be either *reflected* or *absorbed*. The angle of reflection is equal to the angle of incidence. The reflection is said to be regular, when the reflected light from an opaque body with a polished surface, produces images of objects placed in front of it; by multiplying such

surfaces, the reflected images are broken ; and, if the surfac be rough, no image is formed, the light is scattered, and i reflection is irregular. It is by the reflection of the ligl which impinges upon non-luminous, opaque, or transparei objects, from luminous bodies, that the former are rendere visible. Such objects, when they reflect light, completely almost completely, present a white or whitish appearance but, if there is complete or almost complete absorption light, they assume a black or blackish appearance. Tl interception of a portion of the rays of light by opaque bodie is the cause of shadows. When light falls on a transluce body, it is partly reflected, partly transmitted, and partl absorbed ; when it falls directly on a transparent body, suc as air, water, or glass, it is almost all transmitted ; but al sorption of some rays takes place.

Light is either *colourless* or *coloured.* White or colourle light, when reduced in intensity, forms a bluish grey tin gradually passing into blackness, which is usually regarded dependent on the relative or nearly total absence of ligh Black, however, is by some considered to be a positive sensatio

Luminous bodies generally give off rays of light compose of several colours. Thus, solar light, though apparently whit may be *decomposed*, by aid of a prism, into several coloure lights. When a small beam of solar light, admitted through circular opening in a shutter or other septum, falls on one sic of a prism, or three-sided piece of glass, its component rays a so *dispersed* or *spread out*, that if an opaque screen be place behind the prism, an *elongated* luminous image is produce This, which is named the *prismatic solar spectrum*, is n white, but coloured, like the rainbow, presenting bands violet, indigo, blue, green, yellow, orange, and red. The colours appear to consist of various combinations of thr different coloured lights, viz. red, yellow, and blue, or, accor ing to Sir J. Herschel, red, *green*, and blue, which therefo are named the three primary colours. Others maintain th the seven colours of the spectrum, as they cannot be furth analysed, are the primary, simple, optical, or homogeneo colours.

The different coloured lights are said to differ as regar the number of undulations of the hypothetical luminifero ether which excites them. The extreme red rays of the spe trum, for example, are calculated to undergo undulatio numbering 399 billions in a second ; whilst the undulatio

of the other colours of the spectrum are said to increase *progressively* in number, the extreme violet rays performing 831 billions of undulations in the second. The more numerous the undulations, the shorter are their component waves. Colour *in the eye* is due to *specific sensations* in the retina, excited, according to the theory just mentioned, by undulations of different velocity and length; yet why such relations of colour to differences in the number and measurement of the undulations, should exist, is not obvious.

Besides the visible rays, or rays capable of exciting luminous sensations in us, solar light contains certain *invisible rays*, or rays incapable of exciting such sensations, excepting under certain conditions. These rays are also dispersed in the prismatic spectrum, and project, some beyond the violet end, and some beyond the red end, where they form the so-called ultra-violet and ultra-red rays. It may be conceived that these rays undulate, in the former case too rapidly, and in the latter too slowly, to act upon the retina.

There are certain bodies, such as fluor-spar, and many decoctions of organic substances, such as the bark of the horse-chestnut, and the seeds of stramonium, also an alcoholic solution of chlorophyll, and, more especially, a solution of sulphate of quinine in water, which give rise to the formation of internal colour from the passage through them of solar light. The colour, in the case of a solution of quinine, has a beautiful pale blue tint; in other solutions, it may be yellow, yellowish orange, or red. This appearance of colour is known as *fluorescence*, and is produced by a change in the condition of the transmitted light, caused by the substance experimented on, and named *internal dispersion* (Stokes). The rays concerned in this phenomenon, exist also in the coloured prismatic spectrum, but they pass considerably beyond the extreme violet end. They constitute, under ordinary circumstances, invisible ultra-violet rays. When, however, a solution of quinine is held beyond the violet end of the spectrum, it becomes bluish or fluorescent, thus rendering these peculiar rays visible; so also when a sheet of paper, moistened with a solution of quinine, is held in the same position, it becomes beautifully luminous. Clear water and ordinary white paper, held in the same place, are not illuminated. The electric light contains many of these invisible rays.

Again, beyond the red rays of the solar and electric spectra, there are invisible rays, some of which are found, in

decreasing numbers, in the rest of the spectrum. These rays give rise to the remarkable phenomena occurring at this end of the spectrum, known under the name of *calorescence* (Tyndall). By passing the rays of the electric light, brought by means of a mirror to a focus, through a solution of iodine in bisulphide of carbon, the luminous rays are completely stopped; but certain invisible rays, which, in the electric and solar spectrum, are found chiefly near, and beyond, the red end of the spectrum, continue to pass, and produce at the focus, a heat sufficiently intense to set fire to combustible substances. The phenomena of calorescence occurring at, and beyond, the red end of the spectrum, have been compared with those of fluorescence at, and beyond, the violet end. The combustion of oxidisable substances by these dark rays, affords an example of the conversion of obscure radiant heat into light.

These heating rays have been called *calorific* rays; whilst certain of the rays at the violet end of the spectrum, are called *chemical* or *actinic* rays, on account of their power of exciting chemical or photographic action. The coloured rays are named *colorific*.

Light is said to undergo decomposition by *absorption*, as well as by dispersion through a prism. Thus, the great variety of colour presented by opaque bodies when viewed by solar light, is due to the absorption by them, in most variable proportions, of the rays of one, or more, of the three, or seven, primary colours, and the reflection of the remaining rays. In this manner, a blue body is said to absorb, more or less completely, the red and yellow, and to reflect the blue rays; a red body absorbs the blue and yellow, and reflects the red; whilst a yellow body absorbs the red and blue, and reflects the yellow rays. Secondary colours, or compounds of two primary colours, are produced, when a body absorbs one primary colour and reflects the other two; thus the absorption of the blue rays, and the reflection of the red and yellow, give an orange colour; in the same manner, the absorption of red alone gives a green colour, and the absorption of yellow, a purple colour. Tertiary colours, as olives, greys, drabs, are produced when the three primary colours all undergo more or less absorption and reflection. That colour which is necessary, in regard to another, to complete a white light, is called its *complementary* colour; thus orange is the complementary of blue, and blue of orange; again, yellow and purple, and red and green, are, in the same manner, complementary colours. Such complementary colours may be primary

or secondary. If decomposition, by absorption, takes place of all the white light reflected from the surface on which it falls, the colour of the object is intense; but if part of the white light be not decomposed, the reflected colour is diluted by it, and is much less intense. Translucent bodies may decompose white light, in this manner, both reflecting and transmitting various colours. Those transparent bodies or media, which, besides transmitting light, cause its decomposition by absorption, are both coloured and transparent. It has already been mentioned, that absorption of some of the rays always takes place, when light passes through a body, however great its transparency; it is thus that the phenomena of aërial perspective are produced. The rays given off by artificial lights present many varieties in colour. Some are monochromatic, giving out but one colour. Their calorific or heating power, and their chemical action, are also exceedingly different. All such artificial rays are less powerful than the solar rays.

Rays of light, as already stated, travel in straight lines; and so long as they pass through a medium of uniform density, and also when they pass from a rarer into a denser, or from a denser into a rarer medium, as from air into glass (Diagram H, P), or from glass into air, *p*, in a direction *perpendicular* to the surfaces of the media, they continue to move on in straight lines, P *p*. But when rays pass obliquely, O, from one medium into another of different density, they are *bent* out of their straight course, undergoing what is called

Diagram H.

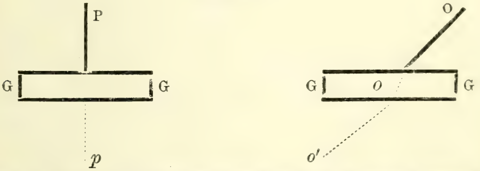


Diagram H. Showing simple refraction of light. G, G, piece of glass. P, *p*, perpendicular ray of light, passing from air into glass, and from glass into air, without change of direction. O, oblique ray bent, on passing from air into glass, *o*, and again bent, *o′*, on passing from glass into air.

refraction. When the rays pass from a rarer into a denser medium, O, *o*, they are bent *towards* a line perpendicular to the surface of the media, at the point of incidence; but when

rays pass from a denser into a rarer medium, o, o', they are bent *from* that perpendicular. The incident and the refracted rays always lie in the same plane. The refractive powers of different media, present considerable differences; thus the refractive index, or relative refractive value of air, vacuum being taken as 1, is 1·003, of water 1·33, of flint glass 1·642, of the diamond 2·755. The amount of refraction increases with the obliquity of the incident rays; this increase follows 'the law of the sines.' The refractive power of a medium increases generally with its density, and with the retardation of the light passing through it; the refractive power of combustible bodies is, however, greater than their density would indicate. The spreading or *dispersion* of the white solar beam by a prism, into the coloured spectrum, already described (p. 546), is explained by assuming that its different coloured rays, have different degrees of *refrangibility.* The violet, or most rapidly undulating rays are most bent out of their straight course, whilst the red, or more slowly undulating rays are the least easily refracted or turned aside.

When parallel rays fall directly upon a *double convex* glass *lens*, such as a common pocket lens, i. e. upon a refracting medium having two spherically convex surfaces, the ray coinciding with its axis, passes through, unchanged in direction, without undergoing any refraction; all the other rays, however, are twice refracted, first, on entering, *towards* a perpendicular to their point of entrance into the lens, and then, on issuing, *from* a perpendicular to their point of exit from the lens. These refracted rays, through whatever part of the lens they pass, meet the central rays at a certain point, called the *principal focus* of the lens; the distance of this from the lens, is called its proper *focal distance*, and is determined by the degree of convexity and the refractive power of the lens. As a lens acts either way, it has two principal foci, one opposite the centre of each surface. When the rays of light proceed from a radiant point, situated in one principal focus of a lens, and pass through the lens, the emergent rays are parallel, just as parallel rays converge to the principal focus. When, however, the radiant point is further from the lens than its principal focus, but not so remote that the rays issuing from it, enter the lens in parallel lines, then the rays *converge* to a point or focus, which is nearer the lens, the greater the distance of the radiant point from its principal focus.

When an object (Diagram I) a, b, c, is placed in front of a

lens, l, so that the rays of light emitted from its several points, diverge as they fall upon the refracting surface, those which proceed from the central point of the object, b, form a *conical pencil* of rays, called a *direct* pencil; all the divergent rays of this pencil, after having undergone refraction, converge on the other side of the lens, meeting the central ray, which has passed through without undergoing any change in direction, at, or near, a *common focus*, b'. The rays from all the other points of the object, form more or less *oblique* pencils. Those oblique pencils which proceed from the extremities or circumference of the object, a and c, undergo similar, though not such regular refraction as the divergent rays of the direct pencil, and after passing obliquely through the lens, converge to their respective *common foci*, a', c', on the *opposite* sides of the common focus of the direct pencil, b. In the same manner, all the rays proceeding from points between the centre and the extremities or circumference of the object, after being refracted, converge to their respective intermediate *common foci*, so that an *inverted* image, a' b' c', of the object, a b c, is thus formed. The formation of such an inverted image, may be readily shown by holding a lighted candle on one side of a lens, and a screen of white paper on the other; it is of special in-

Diagram I.

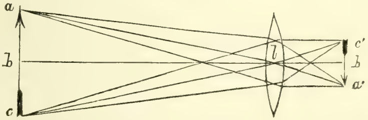


Diagram I. Diagram, illustrating the formation of an inverted image of an object in the focus of a double convex glass lens. l, the lens seen edgeways. a, b, c, an arrow representing the object. a', b', c', the inverted image of the same. a, pencil of rays, from the point of the arrow, refracted on entering, and emerging from, the lens, to meet in the point a'. c; another pencil of rays, from the opposite end of the arrow, acted on in a similar manner, and converging at the point c'. In order to avoid confusion in the diagram, only the central ray, of the pencil from the point b, is here shown; it alone undergoes no refraction.

terest to the physiologist, for this optical phenomenon actually takes place in the eye.

In the production of images by artificial lenses, there are several sources of imperfection. It has already been mentioned, that the different coloured rays into which solar light may be decomposed, have different degrees of refrangibility;

it is in consequence of this unequal refraction, that the images of bodies illuminated by solar or other compound light, formed by an ordinary lens, are surrounded by a fringe of prismatic colours. This defect is called the *error of dispersion* or *chromatic aberration.*

The degree of refraction of the rays which fall on the curved surface of a double convex lens, becomes relatively greater, the greater their distance from the axis of the lens, because they fall upon, and issue from, its surfaces, with greater and greater obliquity. Hence, the peripheral rays are brought to a focus sooner than the central rays, so that every part of the image, becomes more or less indistinct and confused. This is called *spherical aberration.* The effect on a small pencil of light, is the production of the so-named *circles of dissipation.*

By cutting off the peripheral rays, by means of perforated stops or *diaphragms*, both chromatic and spherical aberration may be diminished. They may be almost completely corrected, by building up lenses of two pieces of glass, having different curves, and also different dispersive powers, so that the dispersive and undue marginal refractive effects of one portion of the lens, are counteracted by the influence of the other. Such lenses are called *achromatic.*

If an object be situated at such a distance from the lens, that the rays issuing from it are parallel, the best image is formed in the principal focus of the lens. The nearer the object approaches the lens, the more the focus recedes, until at last, the object having reached the principal focus of the lens in front, the rays emerging from the lens become parallel, and accordingly, no image is formed. Hence, in order to obtain a distinct image of any object, the distance between the lens and the screen for the reception of the image, must be varied, that is, increased or diminished, according to the nearness or distance of the object. In optical instruments, provision is made for the proper adjustment of the *focal distance*, by having the lenses, or the screen, made movable. The defect arising from imperfect adjustment of the focus, is known as *distantial aberration.*

The size of the image varies, of course, according to the distance of the object, being smaller in proportion to the greater distance of the object. The degree of convexity of the lens also affects the size of the image; for the greater the convexity of the lens, the shorter is the focal distance, and the smaller the image produced.

When the rays from a straight line, or from a plane surface, placed parallel with the surface of a double convex lens, pass through it, the image is always curved, or concave, towards the lens; and if the screen for its reception, be a plane surface, this image is defective, either at the extremities or margins, or else in the centre. This, the error from *curvature*, may be obviated by making the screen concave.

The error called that of *distortion*, is due to the varying distances of the parts of the same object; it therefore chiefly affects the extreme marginal rays proceeding from very long straight objects. It is on this account, that the images of the parts of such objects, which lie near to the margins of the lens, are proportionally somewhat smaller, than those of the parts lying opposite the centre of the lens.

The errors of curvature and distortion may be diminished by limiting the operation of the lens to its central part, by cutting off the marginal rays with a perforated diaphragm.

Another imperfection, called the error of *confusion*, is due to the increasing irregularity of the refraction undergone by those rays which fall with greater and greater obliquity on the lens. If the marginal rays are intercepted, this error may be diminished; and if the position of the lens be so changed, that the rays fall on it directly, instead of obliquely, it is entirely obviated.

A *camera obscura* is a dark box or chamber, painted black in its interior, and having, in its front, an aperture fitted with a double convex lens, made to slide in and out, and, at the back, a screen of some semi-opaque substance, such as ground glass, or tissue paper. When an object is placed in front of the lens at a suitable distance, an *inverted* image of it, is projected on to the screen. The distinctness of this image may be diminished or increased, by changing the distance of the lens from the screen; and the introduction of a perforated diaphragm of blackened cardboard, or metal, between the lens and the screen, by cutting off the aberrant marginal rays, will also improve the distinctness of the image, and, at the same time, regulate the quantity of light admitted into the camera. Such a chamber, filled with water instead of air, having a concavo-convex lens fitted into the aperture in its front, and provided, in its interior, with a double convex lens, placed behind a perforated diaphragm, would closely resemble, in its optical arrangements, the globe of the eye, and would form, on the screen behind, inverted images of objects situated in its front.

Sight.

The eyeball, fig. 83, is a natural camera obscura; it is a dark chamber, coloured black, or brownish, within, by the choroid pigment; in front, it presents a convex, transparent, portion, the cornea, *c*, for the admission of light into its interior, as well as for its partial refraction; certain other fluid and solid refractive media, viz. the aqueous humour, *a*, crystalline lens, *l*, and vitreous humour, *v*, are superadded; of these, the crystalline lens is the most important, and represents the internal lens of the water camera obscura; the perforated diaphragm is represented by the iris, *i*, and pupil; lastly, the retina, *r*, occupies the position of the recipient surface or screen. To complete the comparison, when an object is placed in front of the eyeball, at a suitable distance, an *inverted* image of it, is projected on to the retina (see the arrow and its image). This image cannot be seen in the *living* eye; but it may be demonstrated in the human eye, and in the eyes of the larger quadrupeds, taken out after death, on removal of a part of the sclerotic and choroid coats from

Fig. 83.

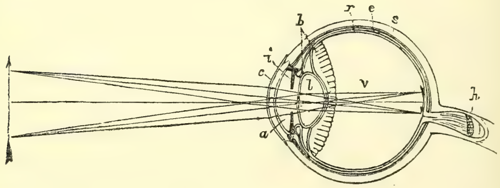


Fig. 83. Diagrammatic section of the eyeball, showing the position of its parts, and the mode of formation of the inverted image of an object on the retina, at the back part of the eyeball. *c*, the cornea. *s*, the sclerotic. *e*, the choroid. *b*, the ciliary processes. *r*, the retina. *a*, the aqueous humour. *l*, the crystalline lens. *v*, the vitreous humour. *i*, the iris.—The position of the ciliary ligament, from which the ciliary muscle takes its origin, is at the junction of the cornea, sclerotic, and iris. *h*, the optic nerve. The arrow, with the lines representing pencils of light, and the inverted arrow on the inside of the back of the eyeball, may be compared with the same parts in Diagram I. p. 551.

the back of the eyeball, and even without such dissection, in white rabbits, and other small albino quadrupeds, in which the coats of the eyeball are transparent.

But the eyeball differs, as we shall see, from an artificial camera obscura, in many ways. Its form is globular, not cubical, so that its screen presents a concave surface; its chief refracting medium, the crystalline lens, is capable of special adjustment for objects at different distances; the eye is also corrected for the aberrations of ordinary lenses; its diaphragm has a self-regulated aperture of variable size; and lastly, the recipient screen is a sensitive surface, which becomes excited by the image thrown upon it, in such a definite manner, that distinct and corresponding visual impressions are thereby produced in the sensorium, conveying to the mind, impressions of *light* and *shade*, *form* and *colour*.

The eye acts upon light like a compound lens; it consists, indeed, of a compound system of refracting media. Thus the cornea forms a *meniscus*, the aqueous humour, a *convexo-concave*, the crystalline lens, a *double convex*, and the vitreous body, a *concavo-convex* lens. The refractive power, or index, of air being taken as 1·003, and that of water, as 1·33, the refractive index of the cornea is 1·33, of the aqueous humour, 1·34, of the capsule and outer layers of the lens, 1·35, of the succeeding layers of the lens, 1·38, of the nucleus or centre of the lens, 1·41, and of the vitreous humour, 1·35. The mean refractive power of the lens, is, by some, estimated as high as 1·45. Rays of light passing from one medium to the other, within the eye, are not refracted, according to the above-mentioned co-efficients, which refer to the refractive powers of the several parts, in regard to rays passing from a vacuum. The cornea first refracts the rays, and the aqueous humour may be taken as a part of one system with it; the lens acts as a second system, and the vitreous humour as a third. The rays, on entering the cornea from the air, are powerfully refracted *towards* the perpendicular; in passing from the aqueous humour into the lens, they are again refracted *towards* the perpendicular, but only in proportion to the *relative index* of refraction of the several media, found by dividing the greater by the smaller co-efficients; on escaping from the lens into the vitreous humour, they are refracted *slightly from* the perpendicular, according to the relative index of refraction of those two parts. These facts, the varying refractive powers of different portions of the lens, and the not absolutely perfect centreing of the several systems of refracting media in the living eye, render it impossible to attain mathematical exactness as to its dioptric action.

The manner in which the eye, regarded as an optical instrument, corrects the errors or aberrations to which such instruments are liable, is most remarkable.

The density and refractive power of the crystalline lens are gradually diminished towards its borders, so that the tendency to over-refraction in that portion of it is counteracted, and thus, as well as by the aid of the peculiar curves of its two surfaces, *spherical aberration* is probably absolutely corrected. The *dispersion*, or *decomposition*, of light in the eye, is very slight; and different and mutually corrective dispersive powers of the cornea, the aqueous humour, and the lens with its capsule, probably correct *chromatic aberration*. It should be added, that the exclusion of the marginal rays by the iris, diminishes the tendency to both the preceding defects. But under certain circumstances, *chromatic* vision, or the perception of coloured fringes at the margins of objects, occurs; for example, when the eyes are not correctly accommodated to a near object; also when one half of the eye is covered by a dark screen. In the latter case, the corrective effect of one half of the lens on the other half, by its opposite dispersive influence over the rays of light radiating from any given point of the object, no longer takes place.

The errors of *distortion* and *confusion*, are likewise diminished by the exclusion of the marginal rays by the iris; but they are not noticeable in vision through the central part of the eye, nor in lateral vision. The error from *curvature*, is corrected in the eye, by the concave shape of the retina.

The *optic centre* of the eye, is a point in its antero-posterior axis, at which the rays of light intersect each other, as they cross to produce an image; and the distance between this point and the retina, must be adjusted to accommodate vision for objects at different *distances*. If one eye be closed, and the other be turned towards two objects placed one in front of the other, in the same line, and at a certain distance apart, the rays proceeding from the two objects, meeting at different foci, the retina does not receive a distinct impression of either; but *circles of dissipation*, as they are termed, form around the images of the objects. If, however, the eye be directed first to one, and then to the other, object, they are both distinctly perceived in succession. In such acts, one is conscious of certain *change and effort, within the eye*. When the eyes are directed from a distant to a near object, the change is apparently due to some internal muscular contraction, which ceases the

moment distant objects are looked at, the parts then resuming their natural and unconstrained position. The sense of fatigue, which always attends near vision, if long continued, is immediately relieved when the eyes are directed to distant objects, the state most commonly regarded as that proper to the eye when at rest.

Concerning the nature of the changes which the eye undergoes, in its adjustment for different distances, various theories have been advanced. According to one view, the adaptation of the eye to distance is effected by means of changes in the condition of the *iris*, inasmuch as in near vision the pupil is contracted, and in distant vision dilated. The contraction of the pupil, which always takes place when near objects are viewed, may, by excluding the marginal rays, help to prevent the formation of circles of dissipation, and thus to render the images of objects more distinct. On this principle, a small object held close to the eye, and therefore seen indistinctly, may be rendered distinct, by looking at it through a small pin-hole in a card; this cuts off the marginal rays; at the same time, the object appears less bright, and also magnified, because its image on the retina is larger, owing to its proximity to the eye. The contraction of the pupil is not, however, the sole change that takes place in near vision, and certainly not the efficient change; for on looking at a bright luminous body situated at a great distance, the pupil contracts, whereas if the eye be directed to a near object of feeble luminous power, the pupil dilates. Moreover, the adjustment of the eye can be effected, even when looking through an unchangeable pin-hole in a piece of paper; further, in cases in which the iris is wanting, or in which it has been entirely removed, the power of adaptation of the eye has remained perfect; and lastly, in long-sighted persons, although the pupil may contract with great vigour, yet near objects are very indistinctly seen.

The movements of the iris under the several above-mentioned conditions, seem to be *consentaneous*, being primarily regulated according to the quantity of light entering the eye, which is relatively more intense, from near objects.

The adaptation of the eye to vision at different distances, has been referred, by some, to alterations in the distance between the optic centre of the eye and the retina, produced by the *pressure* of the ocular muscles *upon the eyeball*. Thus it was maintained, that, in near vision, the antero-posterior diameter of the eyeball, is lengthened by the action of these

muscles, according to some by the recti, according to others the oblique muscles. But to be efficient in accommodati the eye to the necessary distances, such elongation shortening of the eyeball, must be greater than can possib occur in it. Moreover, in cases of paralysis of the re muscles, the power of accommodation of the eye to distan is not impaired, and it has even been proved, that the muscles are unable to produce any appreciable change in t form of the globe. Nor can the adjustment of the eye regards distance, be owing to the action of the oblique muscle for under the influence of belladonna, not only does the pu dilate, but the normal adaptive power of the eye, is lessene although the oblique muscles remain unaffected, for the ey can still perform all the movements dependent on them.

The necessary adjustment has also been attributed to elongation of the distance between the retina and the opt centre, by a *forward movement of the crystalline lens* as whole, but such a movement is not known to occur.

This accommodation of the eye has also been ascribed *changes* in the degree of convexity of the *cornea*, effected b the ocular muscles; and, as the refractive power of this tran parent coat, and of the aqueous humour behind it, is so muc greater than that of air, a very slight increase in the convexit of the cornea, would be sufficient to account for the whol adjusting power of the eye for near objects; but the convexit of the cornea is said to undergo no change, being the same i near as in distant vision. This and the preceding explanatio are further opposed by the facts of a case, in which, althoug there was paralysis of the third nerve, and consequently of a the ocular muscles, excepting the superior oblique and extern rectus, the power of accommodation was unimpaired (Vo Gräfe).

That some change in the position or form of the crystallin lens, is intimately connected with the power of acommodatior is shown by the fact, that when this body is removed, a operation performed when it becomes opaque, constituting th disease known as *cataract*, the power of accommodation i almost wholly lost. It is now, indeed, generally admitted, tha the adaptation of the eye to vision at different distances, or th correction in it of *distantial aberration*, is due to changes i the *shape of the lens*, and that, in near vision, the *convexity of it anterior surface becomes much increased*, so that a forward move ment of this surface ensues, the convexity of its posterior surfac

remaining unchanged (Helmholz). If, in a dark room, a lighted candle, or any other luminous body, be held on one side of the eye, at a distance of about 18 inches, the observer, standing on the opposite side to the light, will see three images of the candle; an anterior erect one, reflected from the surface of the cornea, a *middle*, also erect, image, reflected from the anterior surface of the crystalline lens; and a posterior inverted one, reflected from the posterior surface of the same. The light and the observer should form an angle of about 20° with the eye examined. The first two images are erect, because the cornea and anterior surface of the lens, are convex reflecting surfaces; the third image is inverted, because the posterior surface of the lens acts as a concave reflector forwards. The anterior erect image is the brightest and the clearest of the three; the middle erect image is the largest, the least defined, and the least luminous; the posterior inverted image is the smallest, and intermediate in clearness between the other two. When the eyes are turned from a distant to a near object, the anterior erect, and the posterior inverted image, undergo no change of position, but the middle erect and least luminous image advances somewhat towards the anterior erect image; at the same time, the pupillary margin of the iris undergoes a slight forward inclination, approaching the cornea. Unless the change just mentioned in the middle image, be owing to some other conditions, such as an alteration in the position of the eyeball, or an increase in the convexity of the cornea, either with, or without, a forward and backward movement of the lens, it must be produced by some alteration in the form of the anterior surface of the lens itself. No change in the position of the eyeball, however, is necessary in the act of accommodation; the cornea presents no change in its convexity, such as has been supposed to be produced by the muscles external to the eyeball; any assumed movement of the lens, as a whole, forwards and backwards, is inconsistent with the fact that, according to the best observers, the posterior surface of the lens does not shift its position. The phenomena actually observed, can therefore only be explained by supposing that an alteration occurs in the convexity of the anterior surface of the lens.

An instrument named the *ophthalmometer* has been used, to overcome the difficulties of ascertaining and measuring the minute changes in the relative shape and position of the two images of the flame reflected from the anterior and posterior surfaces of the lens, in the experiment just referred to; and

many most careful determinations of the actual changes which take place in the lens, in the position of the ciliary processes, and in the condition of the iris, have now been made. An increased convexity of the anterior surface of the lens, a forward movement of this surface, so that it approaches the cornea, and a necessary increase in its antero-posterior axis, have thus been noticed. The radius of its anterior surface is diminished, and its vertex approaches the cornea. In the normal eye, the radius of the curve of the anterior surface of the lens, is said to measure 8·8 millimetres in distant vision, and 5·9 in near vision; in the former case, the distance of the anterior surface of the lens from the surface of the cornea is 3·9; in the latter, 3·4 millimetres. The posterior surface of the lens, is said to undergo but little, or, according to the best authorities, no change either in shape or position. By some, however, a slight forward movement of the lens is supposed to occur in near vision. During near vision, the pupil contracts, whilst the pupillary margin of the iris moves forwards, and its attached border or rim falls backwards (Helmholz). On this point, however, contrary statements have been made; for the plane of the whole iris, is said by Knapp to move forwards $\frac{1}{12}$th of an inch; whilst, according to Czermak, it undergoes no change, remaining perpendicular. It is, moreover, stated, that, in near vision, the points of the ciliary processes recede from the margin of the lens (Becker). In accommodation for distant vision, on the other hand, the pupil dilates, the inner border of the iris falls back, and the points of the ciliary processes are said to approach the margins of the lens.

The altered shape of the anterior surface of the lens, now generally admitted to be the essential change in the accommodation of the eye for near vision, is attributed by Helmholz, the originator of these researches, to joint muscular and elastic action; whilst the restoration of the lens to its shape when at rest, is supposed to be due to elasticity alone. According to him, the lens, when at rest within the eyeball, is subjected to the tension of an elastic zone connected with its margin, which maintains its anterior surface somewhat more flattened than it would be, if not so acted upon; the elastic zone here spoken of, seems to coincide with the so-called highly elastic suspensory ligament of the lens. When, however, the eye is turned to a near object, the ciliary muscle is supposed to contract, to draw forward the choroid coat, and, with it, the hinder margin of the elastic zone, which is thus relaxed, and

so its effect in flattening the lens is counteracted, and the lens, by its own elasticity, becomes more convex in front. According to this view, therefore, the active agent in near accommodation, is the *ciliary muscle*, which sets free the elasticity of the lens; and the feeling of effort experienced in such adjustment, must be chiefly due to the action of that muscle; whilst distant accommodation involves only the employment of the elastic force of the suspensory ligament of the lens.

Though the explanations of Helmholz are generally accepted, it is maintained by some, that, in near vision, the lens undergoes an alteration both in shape and position, through the influence of the ciliary muscle, or of some simultaneous pressure, exercised by the iris also, upon the margin of the lens. By this pressure, the substance of the lens is supposed to be subjected to the degree of tension necessary to increase its convexity; whilst, in distant vision, the muscular parts are supposed to relax, and the lens, by its own elasticity, to recover its flatter form (H. Müller and Cramer). The swift forward movement of the lens is supposed to be owing to the ciliary muscle drawing forward the choroid coat, which acts on the vitreous humour, and this, in its turn, on the lens. Lastly, an opinion recently entertained, is, that the eye is at rest only when objects situated at medium distances are looked at, and, that, in the production of the changes in the eyeball, necessary for near vision, the circular fibres of the iris contract, whilst the radial fibres contract when distant objects are viewed (Langenbeck, Henke). If such be the case, it is difficult to account for the fact, that the sense of fatigue, which, as already mentioned, always attends near vision, immediately disappears on directing the eyes to distant objects. Moreover, on opening the eyes after they have been closed for any length of time, distant objects are those most clearly perceived.

There can be little doubt, however, that, whatever may be the nature of the changes in the lens, by which the necessary adjustment is effected, they are accomplished *chiefly*, as is now generally supposed, by the agency of the fibres of the ciliary muscle, or so-called tensor of the choroid, with which the iris may in some way cooperate. The movements themselves, though instigated by the will, and assisted by sensation, are automatic. As is well known, atropine, the active principle of the atropa belladonna, or deadly nightshade, whether locally applied, or taken internally, dilates the pupil; but it also destroys the power of accommodation of the eye to

distances, distinct near vision being rendered impossible. The extract of the Calabar bean, on the other hand, contracts the pupil, and, at the same time, the power of distinct distant vision is diminished, whilst that of near vision is increased; the power of accommodation is not, however, entirely paralysed. The visible effects of these substances are upon the iris; but it does not follow that they are limited to the muscular fibres of that structure, so that the changes in the accommodating power of the eye, produced by them, must not be entirely attributed to the dilatation or contraction of the pupil. There probably occur simultaneous effects on the ciliary muscle, the conjoint results being, not only a change in the size of the pupil, but also in the form of the crystalline lens. Opium is another medicine which contracts the pupil, but its effects on vision, do not appear to have been accurately studied. Hydrocyanic acid dilates the pupil widely, the circular rim almost disappearing.

It is not yet understood how these medicinal agents affect the pupil. Atropine, for example, may cause dilatation, either by paralysing the oculo-motor nerve, or its nervous centre, which might be termed *passive* dilatation, or by stimulating the sympathetic nerve or nervous centre, constituting an *active* form of dilatation, or in both ways simultaneously. But atropine is found to influence the state of the pupil, after division of both the above-named nerves, and even after excision of the eyeball. It is possible that these agents affect the pupil only indirectly, by their blunting, or exalting, the sensibility of the retina, and so causing, in the former case, dilatation, in the latter, contraction, of the pupil.

The accommodation of the eye in viewing near objects, is known as *positive* accommodation, that, in looking at distant objects, as *negative* accommodation. The act of accommodation is effected more rapidly, when the eye is turned from a near to a distant object, than when it is directed from a distant to a near one. The time required is probably modified by age, practice, and other circumstances; in old age, for example, more time is occupied in accommodating the eye for near objects, than in childhood. The accommodation, when the eye is turned from an object at 60 feet distance, to one at $4\frac{1}{2}$ inches, is said to take place in $\frac{9}{10}$ths of a second; whereas only $\frac{7}{10}$ths of a second elapse in changing the accommodation from $4\frac{1}{2}$ inches to 60 feet (Vierordt). It would seem, however, that, in the case of short distances, the time necessary

is relatively much greater; for according to other observations, the accommodation from 17 inches to $4\frac{1}{2}$ inches, requires as long as 2 seconds: that from $4\frac{1}{2}$ to 17 inches, $1\frac{1}{5}$th of a second (Aby). Between a distance of 200 feet and the horizon, all objects are seen equally clearly without change of accommodation; but, at nearer distances, the necessity for exact accommodation increases, and, in very near vision, it is absolutely essential, one object only in the so-called *line of accommodation* (Czermak), being clearly visible at the same time.

The range of healthy vision, or the sight of *hemitropic* eyes (Donders), is limited by two points, named the *far point*, or point of rest, and the *near point*; the ordinary limits of near vision, or close focal adjustment, and of distant vision, are said to be from about five inches to indefinite distances, according to the intensity of the light. The ordinary focal distance for easy, clear, vision, as in reading, is about eight inches. But the proximity of the near point, is greater in early life, and afterwards progressively diminishes. Thus, at the 10th year, it is only $2\frac{2}{3}$ of an inch in front of the cornea; at each succeeding decennial period, its distance is $3\frac{5}{9}$, $4\frac{4}{5}$, $6\frac{6}{7}$, 12 and 24, till at the 70th year, its distance from the front of the cornea is 144 inches (Fellenberg). The far point may be said to have no limits. Under the action of atropine, the near point recedes, and gradually reaches the far point. The Calabar bean lessens the distance of the far point, and frequently also that of the near point.

In certain persons, the natural range of adaptation of the eye to distance, is defective, and exceedingly limited, so that they are unable to see objects except at certain distances. Such persons are either *short* or *long-sighted.* In long sight, objects are only seen distinctly when at a distance from the eye; near objects, if small, are either invisible, or else only confused images of them are perceptible. In short sight, on the other hand, objects at a moderate distance are invisible or indistinct, the power of distinct vision being limited to objects brought very close to the eye; at the same time, a short-sighted person sees small and near objects very distinctly, better illuminated, and under larger visual angles, and therefore larger and brighter, than other persons.

These abnormal conditions of vision arise from a certain fundamental excess or defect in the refractive power of the eye. In long sight, for example, the cornea is flatter than usual, and the antero-posterior diameter, or optic axis, of the

eye is said to be lengthened; the rays of light do not undergo sufficient refraction, but, instead, converge to a focus *behind* the retina; by the use of convex glasses, the convergence of the rays is increased, and they are brought to a focus upon the retina. In short sight, the convexity of the cornea is too great, so that the rays proceeding from an object, instead of being brought to a focus on the retina, intersect each other at a point *in front* of that membrane; the antero-posterior diameter of the eye is also probably shortened; this defect is corrected by wearing concave spectacles, which cause divergence of the rays, so that the over-convergent effect is counteracted, and the rays are brought to a focus upon the retina. It is probable that not only the curvature of the cornea, but that of the lens also, is peculiar, both in long and short sight. In both conditions, not only are the images thrown on the retina, indistinct, but luminous circles of dissipation are formed upon it. Short-sighted eyes often improve by age, the cornea being said then to become flatter, owing to a diminution in the quantity of the fluids of the eyes. Normal eyes, from the same cause, may become long-sighted in old age.

To determine with accuracy, the focal distance of the eyes, various instruments, named *optometers*, have been invented. A simple plan, devised by Scheiner, is to make two holes with a needle in a card, the distance between which must be less than that between the two pupils. On now looking at a perpendicular line, through these holes, the line appears double if the eyes be too close to it, but single at the distance of perfect or normal vision, which distance is thus ascertained for any particular eyes. It is desirable in the selection of glasses, not to over-correct the natural defect, for this would fatigue, and weaken the eyes still more. The eyeglass, or spectacles, should merely render objects distinct, but not magnify or diminish them. Concave glasses are numbered, according to the distance of their virtual focus from them. By multiplying the normal distance of near vision, say 10 inches, by the distance of clear vision in the short-sighted person, say 4 inches, and dividing the product by the difference between those two factors, the number of the concave glass required, is found; thus, $10 \times 4 \div 6 = 6{\cdot}6$; i. e. about No. 7 glass. The same rule obtains in the choice of convex glasses for long-sighted people. In the normal eye, concave glasses diminish the size of objects looked at through them, because they diminish

the actual size of the retinal image. On the other hand, convex glasses, or lenses, including both simple and compound microscopes, increase the apparent size of objects, by enlarging their images on the retina; they, in fact, enable the eye to see such objects under larger angles, or as if they were very closely approximated to the eye. The necessary dilution of the light, in this process, is met by various contrivances for powerful artificial illumination.

A distinction has been drawn between *short* and *long* sight, or so called *myopia* and *presbyopia*, on the one hand, and *near* and *far* sight, or *true myopia* and *presbyopia*, on the other. The former states depend, as we have seen, on individual peculiarities in the *shape* of the eyeball or its parts; for, besides normally-constructed eyes, there are eyes, the natural foci of which, lie either in front of the retina, helping the eye in near vision, or behind the retina, adapting it for distant vision. The causes may be a greater or less prominence of the cornea, a shorter or longer optic axis, and a greater or less curvature of the lens. Near sight and far sight, depend on defects in the *power of accommodation* of the eye; as, for example, on loss of power in the ciliary muscle and iris, or on diminution of the elasticity of the lens or its suspensory ligament, both of which conditions are found in advancing age. In short sight, the point of nearest vision may be even as close as two inches to the eye; but in near sight, or true myopia, the near point may be 12, 30, or even more inches from the eye. The term *hypermetropia* has been used to designate the condition of long sight, sometimes named presbyopia, which latter term is then restricted to the impairment of vision, as regards near objects, which comes on after a certain period of life, and which is due to a diminution in the range of the power of accommodation (Donders).

In many individuals, the focal lengths of the two eyes, are different, a fact, which escapes attention, unless the difference be very marked. It is worthy of observation, that short-sighted eyes are still *achromatic*, objects seen indistinctly by them, being without coloured fringes. According to Ehrenberg, the absolute limits of vision, are, in no way, dependent on the focal distance of the eyes, and, in individuals possessing ordinary visual powers, present but slight differences.

In some persons, the refractive power of the horizontal and vertical meridians of the eye is unequal. This condition, which is not uncommon, is known as *astigmatism*. It is due

to a difference in the degree of convexity of the cornea or crystalline lens, or of both these parts, in the horizontal and vertical directions, so that corresponding rays passing into the eye, instead of converging to one identical point, meet at two different foci. By means of cylindrical glasses, this imperfection can be corrected.

The *dilatation* and *contraction of the pupil*, which result from variations of light, are purely reflex phenomena. The sensory fibres of the iris, as well as its vasi-motor fibres, are derived from the fifth cranial nerve; irritation of either the first or second divisions of this nerve, causes the pupil to contract on the same side.

The direct effects of heat and light on the iris, in dead animals, have been noticed by Brown-Séquard. If the eye of a rabbit, or other animal, be subjected, shortly after death, to a sudden elevation of temperature of from 50° to 60°, the pupil, if previously contracted, dilates, or, if dilated, it contracts; these effects are explained by supposing that the heat acts more powerfully on those muscular fibres which had previously been at rest. Light causes contraction of the pupil in Mammalia and Birds, for a short time after death; but in eels and frogs, the iris may be so excited even sixteen days after! Yellow light seems to act the most powerfully. This sort of contraction can be induced after removal of the posterior half of the eyeball, so that it cannot be referred to reflex action.

During life, the diameter of the pupil diminishes with increasing light, the amount of contraction being proportionate to the strength and duration of the luminous impression. A direct light acts more powerfully than a slanting light, the sides of the retina being apparently less excitable. When the two pupils are under the influence of different degrees of light, they are still usually of equal size, unless the difference of luminosity be very great. If one eye only be acted upon by light, both pupils contract, the one not exposed to the stimulus rather less than the other. Contraction of the pupil takes place more rapidly than dilatation; and it has further been noticed that the movements of the iris are quicker than those of other parts composed of unstriped muscular fibres. Excessive dilatation of the pupil is named *mydriasis*, and excessive contraction, *myosis*.

The chief object of these changes in the size of the pupil, is to regulate the quantity of light admitted to the eye, and

to protect it against too dazzling luminous rays; they also, in this way, determine the brightness of the retinal images, which become brighter as the pupil dilates, though they may be then less defined or distinct.

As already mentioned, during near vision a consentaneous contraction of the pupil occurs. It has been noticed, indeed, that the pupils also contract when the eyes are made to converge, and, as this convergence always accompanies the act of looking at near objects after distant ones, this likewise aids in inducing the contraction of the pupils necessary for near vision. It is through the oculo-motor nerve, which supplies the sphincter of the pupil as well as the internal recti muscles, that this consentaneous narrowing of the pupil is excited. But the one movement is independent of the other, because the contraction of the iris, and the accommodation movements, occur equally well, when one eye only is used; and, by some persons, the eye can be accommodated without any change in the degree of convergence. Lastly, certain cases have been recorded, in which the movements of the iris were, in some manner, perhaps indirectly, under the control of the will.

The movements of the ciliary muscle, like those of the iris, with which they appear to be consentaneous, are usually involuntary; they are probably, however, sometimes independent of each other. The nerves which regulate the action of the ciliary muscles, are supposed to be branches of the third pair, but this is uncertain. In some exceptional cases, the ciliary muscle has exhibited an apparent subjection to the control of the will.

The nervous centres concerned, are the anterior pair of the corpora quadrigemina; the afferent nerves are the optic nerves; and the efferent nerves are the third cranial, and the sympathetic. The dilatation of the pupil is regulated by nervous influence, conveyed from the spinal cord, through the branches of the sympathetic nerve, which supply the radiating fibres, division of that nerve in the neck being followed by contraction of the pupil, and its irritation by dilatation. The contraction of the pupil is governed by the circular fibres, and is regulated through the third cranial nerve alone. Irritation of the latter nerve causes narrowing, whilst its division is followed by dilatation of the pupil. The diameter of the pupil at any particular moment, however, depends on certain combinations of action of its radial and circular fibres. Its state of complete repose, or quiescent condition, as, for example, when

no light is present, or the optic nerves are diseased or inactive, is that of moderate dilatation. After division of the optic nerve, in an experiment, the same result is noticed; if then, the third cranial, or oculo-motor, nerve, which supplies the circular fibres, be divided, the pupil does not widen; but if the sympathetic, which supplies the radial fibres, be now cut, the pupil slightly contracts. From this it would seem, that in moderate contraction, only the radial fibres are really active.

Of the different portions of the *retina*, the fovea centralis, which is situated in the line of direct vision, is the part most sensitive to light, and is the seat or area of *distinct vision*, both as regards form and colour. At the point of entrance of the optic nerve, the optic colliculus, or optic eminence, which is not in the line of most perfect vision, the retina is incapable of receiving distinct visual impressions. It has indeed been named the *blind spot*. If two small dots be made upon a

piece of paper, at a short distance from each other, and the optic axis of the right eye be directed vertically upon the left-hand dot, whilst the left eye is closed, it will be found, that when the paper is held about four times as far from the eye as the dots are from each other, the right-hand dot will be no longer visible, for its image falls upon the optic eminence. In the same manner, when the image of an object is made, by artificial means, to fall simultaneously upon both optic eminences, no visual impressions are excited by it. Since this portion of the retina, which is thus deficient in sensibility to light, consists only of the diverging fibres of the optic nerve, all the other elements of the retina being absent, whilst that portion of the retina most sensitive to light, viz. the fovea centralis, is destitute of all the retinal elements, except the cones and grey ganglionic nerve vesicles, it would seem that the optic nerve fibres are excited only by the changes induced by luminous rays in some other retinal structures, and are themselves only indirectly excitable by light. The rods and cones alone appear to be the proper recipient organs. The yellow spot, the part most sensitive to light, contains closely-packed cones and ganglionic cells, but is destitute of nerve fibres; whilst at the sides and anterior parts of the retina, the rods become less numerous, and

the sensibility to light is diminished. Moreover, exposure of the optic nerve itself to the strongest light, gives rise to no luminous sensations, and excites no reflex contractions of the iris; besides this, in the eyes of insects, as we shall hereafter describe, the rods and cones only are exposed to the action of light, the optic nerve fibres being covered by pigment. The rods and cones, or perhaps even their outer and more highly refractive segments only, may, indeed, be regarded as the parts which receive the undulatory movements of the luminiferous ether, and modify, or *translate* them, into nervous energy or force, which then manifests itself, by propagation along certain of the radial nuclear fibres to the ganglionic nerve cells, thence to the plexiform fibres of the retina, through these to the optic nerves and tracts, and finally to the optic sensorial centres.

It may here be remarked, that, whilst the parallel *cochlear* elements, the rods of Corti, receive the sonorous impulses at right angles to their own direction, the parallel *retinal* elements, the rods and cones, receive the luminous rays in lines corresponding with their own direction. This difference may be connected with the condition, already adverted to, viz. that the supposed movements of the luminiferous ether are transverse to the direction of the imaginary lines called rays, whilst, as is well known, the movements which produce sound, take place in the direction of the sonorous rays. In both the ear and the eye, therefore, the microscopic recipient organs, connected with the extremities of the nerves, are so arranged, that their proper exciting *motions* do not pass inoperatively *between* them, but agitate them *transversely.*

In the retina of Man and of the Vertebrata, all the light must pass through the nerve fibres, ganglionic cells, and blood-vessels, and also through the granular layer, before it reaches the rods and cones, or true excitable elements. The existence of these last-named structures appears indispensable to distinct vision; their outer free ends form a mosaic surface, on which local points of light fall evenly, and thus excite the sensation of a uniform visual field, having definite points of *locality*, which would be impossible if the light directly stimulated the plexiform nerve fibres; for, in that case, the same fibre would receive numerous luminous impressions along successive points of its course, and so would be excited, without an exact localisation of the sensory impressions. The position of the rods and cones perpendicularly, or nearly so, to the

retinal surface, evidently adapts them for the distinct reception of local points of light, for which purpose the lateral surfaces of the linearly-expanded optic fibres are ill suited. Beyond the rods and cones, is placed the dark choroid coat, the pigment of which is supposed incessantly to absorb the light which passes through, so as to prevent confusion from successive impressions. In Albinos, in whom this black pigment is wanting, vision is imperfect, especially in strong lights, which may even cause pain.

The existence of the so-called blind spot in the retina, does not produce any obvious defect of vision, when both eyes are used, because the image of an object falling on the optic eminence of one eye, naturally falls elsewhere, and on a sensitive part of the retina, in the other eye; and so the blank in vision is filled. In the use of one eye, the defect is partly remedied by the phenomenon known as *irradiation*, hereafter to be explained, and partly by our experience and knowledge of the actual forms of objects; furthermore, any impairment of sight, dependent on the existence of the blind spot, occurs beyond the area of distinct vision, and therefore attracts less attention than it would otherwise do, and is more easily corrected by experience, or by the effects of irradiation. If the fibres of the optic nerve, at the blind spot, were directly sensitive to light, then they would receive at least two impressions—one from their retinal extremities, and the other from the light falling on the optic eminence; such a condition would lead to confused vision.

Müller and other physiologists, however, have denied that the retina at the point of entrance of the optic nerve is wholly insensible to light. They believe that the excitability of the retina is there peculiarly diminished, but that it exhibits, in a marked degree, the phenomenon of irradiation. The vanishing of the dark image of the dot, in the experiment above mentioned, was referred by Müller, to a power, in the retina, of communicating to a smaller portion, a condition affecting a larger part. Thus, when the retina is exposed to two different impressions, one of which falls upon a larger, the other upon a smaller, portion of the membrane, the former impression is, after a time, propagated to the whole of the surface, whilst the latter is no longer perceptible. If, for example, one eye be directed, for a certain time, upon a narrow slip of coloured paper, fixed upon a white ground,—after a brief interval, the image of the former vanishes, the white ground alone being

visible; this is most marked, when the lateral portions of the retina receive the image (Purkinje and Brewster).

In the exercise of the senses of touch, taste, and smell, we refer the sensations excited, to the organ, or part, of the body where the stimulus acts on the extremities of the nerves; but, as in hearing, so in sight, the sensations are rapidly converted into *perceptions*, and are referred, though far more definitely, altogether to the exterior, and, in the exercise of sight, actually to the external objects from which the rays of light are given off. The images formed on the retina, are never referred by the mind, to the interior of the eye, where their existence is not known to the untaught mind, and where, even when informed of the fact, the mind is still unconscious of their presence.

This *outward projection* of our visual sensations, is, by some, regarded as an ultimate fact incapable of explanation; but others believe that it depends upon experience, gained by comparing the results of vision, as regards our own bodies and external objects, with the concomitant results afforded by the sense of touch, aided by movements of the body. Vision, considered as a means of obtaining a knowledge of the presence, form, colour, position, and motion, of external objects, is wholly dependent upon this outward projection of its impressions. Even in excitement of the retina by pressure, electric shocks, or internal stimuli, the luminous impressions produced, are referred to the exterior.

The perception of objects in their *erect position*, through the agency of an inverted image, is intimately connected with this outward projection of vision. The mind, in referring the luminous impressions in the sensorium, to the objects whence the rays of light proceed, follows these latter, as it were, from the retinal image, and views their several focal points in the direction of certain imaginary lines, which are more or less nearly perpendicular to the retinal surface. It has been shown by Serre, in his experiments on the luminous spectra, produced by pressure on the eyeball, and called by him *phosphènes*, that visual impressions are projected from the retina, along certain lines, towards a common centre in the eyeball, or *optic centre*, which he calls the *centre of direction*, and which he locates in the middle of the crystalline lens. Others, however, have variously supposed that these lines, which they name *lines of direction*, meet in front of the lens, in the centre of the pupil, or, behind it, in the centre of the eyeball. Having crossed each

other at the optic centre, these lines emerge from the refracting media of the eye, suffer a slight change in their course, pass outwards to the object, and correspond with the direction in which the central ray of each luminous pencil (fig. 83.) reaches the eye, as it proceeds from the object to the retina. In applying this theory to the explanation of the problem of erect vision from an inverted image, it is supposed that every point of the object (of the arrow, for example) being seen along these lines of visual direction, appears to the mind in its true position in space, and that hence the entire object is perceived *erect*. According to Müller, however, images of objects formed on the retina, may really be *perceived* by the mind in their *inverted* position, but as all objects, including the body and limbs themselves, are thus seen inverted, their relation to each other remains unaltered, and we should be ignorant of this inversion, were we unacquainted with the laws of optics. Some have supposed that the sense of touch corrects a primitive error of ocular observation, or of perception, in the infant ; but to this it may be replied, that the one sense is always in harmony with the other, the image of the hand being inverted, and thrown upon the same part of the retina, as the image of the object to which it is directed. Moreover, it is obvious that the general sense of locality or position of the body, gives rise to the notions and terms, upper and lower, above and below, right and left, and so we regard things as erect or inverted, according to their position in relation to that of our own body. In this way also, we know that to look at something above us, we must turn our head or eyes upwards, and such a movement, not the position of the retinal image, which is unknown to us, determines our notion or judgment of the position in space, in which the object lies as regards our body.

The area of outward visual projection, is named the *field of vision*; its horizontal and vertical measurements have been differently estimated at from 116° to 120° and from 130° to 180° of a circle respectively. Its greater horizontal diameter, is owing to the two eyes being concerned in its production. The horizontal diameter is not constant, but diminishes in convergence of the two eyes. Lines, drawn from the upper and lower, and from the lateral boundaries of this area, to the optic centre of the eye, form angles at that point ; when prolonged backwards to the retina, they also form similar angles. These are the optic or *visual angles* of the field of vision.

The only part of the field in which vision is perfectly distinct, is a small surface, the centre of which corresponds with the hinder end of a line drawn from the yellow spot to the centre of the cornea, i.e. along the visual, or optic axis of the eye. The *area* of the retinal surface which is best fitted for *distinct vision*, is about $\frac{1}{3}$ or $\frac{1}{2}$ of a line in diameter; this corresponds with the breadth of the yellow spot. Around this, is a small circular portion of the retina, known as the *circle of indirect vision*, and, beyond that area, vision becomes less distinct, in proportion to the distance of the retinal image from it. The circle of indirect vision is said to be increased during near vision. We can see distinctly, at one time, about six or eight letters of ordinary type; but the lines immediately above and below, are indistinct. Objects, the images of which are situated at an angle of 50° or 60° from the axis of vision, are seen only in their general outline, while smaller and darker objects may be invisible. The *actual* images on the retina are, however, equally clear at all parts of that membrane, and hence the diminution in the distinctness of vision, must proceed from deficient receptivity of its lateral parts. This is observable in regard to colour as well as form. It is said that the retinal sensibility diminishes more quickly in the upward and downward direction, than laterally. The existence of a limited area in the retina, specially set apart for distinct vision, enables us to concentrate our attention upon special objects in the visual field, undisturbed by the simultaneous images of surrounding objects. Moreover, by this arrangement alone, we are able to direct the optic axes of the eyes in exact and known directions, so as to gain a knowledge of the direction or position of visible objects, and, further, to adjust the axes of the two eyes, so that they shall meet in any given object, a condition essential, as will be presently explained, for the occurrence of single vision with two eyes.

The *adjustment of the optic* axes upon any object, is accomplished by the movements of the body and head, and especially by those of the eyeballs themselves, which are very rapid, singularly free, and perfectly under the control of the will, the globe of the eye turning, like a sphere, upon its poles or axes, as it rests, in its capsule, on its smooth cushion of fat. By means of the complex movements of the two eyeballs, already described (p. 535), the field of vision of each eye, and that of the two combined, is perfectly under our command, so that the optic axes can be made to converge, with the most

extreme accuracy, upon the smallest object which we can see distinctly. This is effected voluntarily, not, however, as a simple direct act of the will upon the ocular movements, but only indirectly, by the mind seeking, through the eyes, the desired attainment of the distinct vision of any given object. The mind, however, is cognisant, through the muscular sensations, that the desired act is performed, and that the position of the eye is duly adjusted. The combination of harmonious movements of the *two eyes*, is beyond our direct control, and is perhaps provided for by a commissural, or other, disposition of the governing nerve-fibres of both eyes, in the oculo-motor nervous centres. As already mentioned, the direction of objects is referred to their correspondence with, or deviation from, the position of the optic axes; and every retinal impression is referred to its proper line of direction in the outer world. The position of these axes, is known to us very accurately, by means of impressions, conveyed through the muscular sense, of the condition of the several muscles of the eyeball. The notion of the *direction* of objects, is therefore not a simple sensation, but the result of a judgment, formed by the mind, from certain impressions conveyed to it.

The *apparent magnitude* of an object, is determined by the size of its retinal image, in other words, by the size of its visual angles, or angles formed in the eye, by lines drawn from its extremities or margins through the optic centre of the eye. When the visual angle of an object is known, the object is said to subtend such an angle. The apparent magnitude of an object, is influenced by its distance from the eye, for the angle it subtends must, of course, be larger, the closer its proximity to the eye. The apparent magnitudes of a small object, close to the eye, and of a large object at a distance, such as a pin and a man, are identical, if they subtend equal angles. The degree of movement of the eyeballs, required to pass from one end of an object to the other, is also a further means of determining apparent magnitudes. The sense of magnitude is more exact in regard to horizontal than to perpendicular lines. It is said to be possible to distinguish between two lines of different lengths, even after certain intervals of time, for example, to the extent of a difference of $\frac{1}{40}$th after the lapse of 3 seconds, and of $\frac{1}{11}$th after 70 seconds. The accordance of the senses of sight and touch, as regards the information which they respectively afford, concerning the size of objects, seems to be the result of experience and comparison; for a person born

blind, who gained sight by an operation, has been said to state that objects known to him by touch, appeared larger than he expected.

Our knowledge of the *real* magnitude, or *absolute* size, of objects, is only arrived at indirectly, and by means of experience and inference, by comparing them with objects, with the dimensions of which we are already familiar, and by taking into account their respective distances.

In the same manner, our visual sensations inform us only of the apparent or superficial shape and colour of objects, of their apparent direction or position in the field of vision, and of their apparent motion in the same. All our conclusions as to their *real* form, colour, position, and motion, are arrived at by observation and comparison of these appearances. For the determination of the apparent qualities of any object, and also of its real size and colour, *one eye* alone suffices; but for the purpose of ascertaining by means of the sight alone, its *real form*, *real position*, and *real motion*, the conjoined use of *both eyes* affords material assistance. In this constant mode of employing the two eyes, their distance from each other, named the *inter-ocular distance*, is of the highest optical importance.

We derive our notions of the *solidity*, *roundness*, or *relief*, of objects, from the combined use of the two eyes; for when one eye alone is employed, we can only see plane figures having two dimensions, viz. length and breadth. For the perception of solid forms of three dimensions, viz. length, breadth, and thickness, within a moderate distance, the optic axes of the two eyes are made to converge, so that straight lines prolonged from them, would meet in the object.

As a rule, an external object forms but a single image in one eye, and the mind, perceiving such single image, refers it to a single object. But there are conditions, in which one eye may receive two or more identical images, from, and of, one external object, and then, unless the mind be otherwise informed of the illusion, such images are referred by it to as many distinct, though exactly similar, objects. For example, if we look with one eye at a pin through two minute holes in a card, the distance between which is less than the diameter of the pupil, the same retina receives, on different parts of its surface, two separate images of the pin, which, accordingly, being outwardly projected along the proper lines of direction, are seen double, though we know the pin to be single. So, likewise, in

the use of the doubly refracting Iceland spar, and of multiplying glasses or reflectors, the pencils of luminous rays from on object, are so refracted or reflected, as to form double, o multiple, images, which are thrown on to different parts o the same retina, and accordingly are seen as multiple images though known, on other grounds, to proceed from one object.

Each retina regards as single, an image formed on any on definite point of its surface; but single objects necessaril form an image in *both* eyes, and hence, for the useful and un deceptive application of vision, the mind must be able t combine the impressions made by these two images, so as no to be deceived into a belief that they proceed from tw objects, instead of from one.

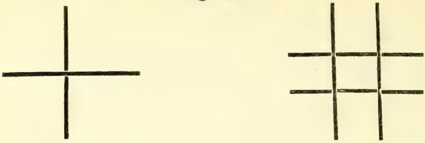
When both eyes are thus directed to any given object, line prolonged from their optic axes, meet at that object, and th two retinal images produced by it, viz. that formed in th right eye and that formed in the left, fall exactly on th centres of the two retinæ. The images of all surrounding ob jects, are received on surrounding portions of the two retina surfaces. Those portions, like the central points themselves are said to *correspond*, though of course, from the complet inversion of the pictures, they are on opposite sides of th centres of the retinæ. The two pictures thus received, ar not seen *separately*, and referred to two sets of objects, bu are *combined by the mind*, and referred to a single set of ob jects. In other words, *single vision with two eyes*, results Sometimes, however, impressions made on the two retinæ, ar not combined, but are separately distinguished by the mind producing the phenomenon called *double vision*. It is probabl that in the infant, double vision, and, therefore, indistinct vision is, at first, the rule, but that, by degrees, the eyes are brough to converge suitably on external objects, and thus single visio occurs. By habit and education, this power is, at length, s confirmed, that we are no longer conscious of perceivin two images, but only experience a singleness of percep tion. When double vision occurs, it is found that the tw eyes are not turned directly towards a given object, so tha lines prolonged from their axes, no longer meet in that object and the images of it, formed in the two eyes, are no longe received on corresponding points of the retinæ.

These *corresponding* or *identical points* of the retinæ, are, b some, regarded as the result of use or habit alone; but, on th other hand, their existence, as fundamentally or primitivel

identical spots, is thought to be proved by the following experiments. If pressure be made, in the dark, or when the eyelids are closed, upon the upper portion of both eyeballs, a *single* luminous circle, named *a phosphène* (Serre), is perceived in the centre of the field of vision below. If the lower part of *both* eyeballs be pressed upon, a *single* luminous circle is perceived in the centre of the field of vision above. Hence the upper portions and the lower portions of the two retinæ, are regarded, respectively, as identical. Pressure upon the inner side of one eyeball and the outer side of the other, produces a *single* circle of light, in a direction opposite to that of the pressure; hence the *inner* side of one retina is said to correspond with the *outer* side of the other. But if pressure be made upon the upper part of one eyeball, and the lower part of the other, *two* luminous circles are seen, one above, the other below; in the same manner, pressure upon the inner sides of the two eyes, produces *two* circles, and so also does pressure upon the outer sides. The upper part of one retina and the lower part of the other, their inner sides and their outer sides, are said therefore *not* to be identical. Speaking generally, those parts of the two retinæ are identical which correspond in situation, in reference to the centre of the eye; thus, the upper portions, the lower portions, the right sides and the left sides, corresponding in this relative position, are identical in sensation. Hence, it has been said that all points of the two retinæ, situated at equal distances from their centres, and lying in the same direction, are identical in sensation, and, when simultaneously excited to action, give rise to the perception of one object. That a general identity of action, or function, of certain parts of the two retinæ, exists, is sufficiently obvious; but that it does not afford the ultimate explanation of the combination of the two images, is shown by the fact that, in stereoscopic vision, as we shall presently explain, the two perspective views of a given solid object, which are necessarily dissimilar, or they would not yield a stereoscopic effect, cannot cover exactly identical parts of the two retinæ, and yet they are combined into one image or impression. Again, images formed on corresponding points of the two retinæ, are sometimes not combined, but are seen double in the visual field, as when we look at one of two objects placed exactly in front of us, between the eyes, the images of the one which is seen double falling nevertheless on exactly identical points of the two retinæ. The same is the case, when we look at one object

with both eyes, but through different coloured pieces of glass

Diagram K.

A  B

It has been shown by Helmholz, that, in double vision, i is not actually vertical meridian lines on the retinæ whic correspond, or are identical, but other lines inclined about $1\frac{1}{4}$ from the meridian, which he calls *apparently vertical* meri dian lines. The horizontal corresponding lines are, on the con trary, actually horizontal. If, for example, as in Diagram K, A across a horizontal line, another be drawn, accurately perpen dicular to it, the right upper included angle appears large than a right angle to the right eye, and less than a right ang to the left eye; the lower angles are altered in the revers manner. Again, if two figures be drawn, having similar hor zontal lines, but crossed by vertical lines inclined at the upper ends, $1\frac{1}{4}°$ left and right, from a central perpendicula then, when the left-hand figure (Diagram K, B) is looked a with the left eye only, the angles formed by the vertical an horizontal lines appear to be right angles; but, when looke at with the right eye only, they appear to deviate from rig angles, and *vice versâ* with the opposite figure. Two suc figures, however, combine stereoscopically, and then mal an impression on the mind, of a figure composed of *perfe squares.* In the act of adjustment necessary for this, not on must the eyes be made to converge, by being rotated on the vertical axes by the internal recti muscles, but the obliq muscles must slightly rotate the balls of the eyes on the antero-posterior, or visual, axes (see p. 534).

That the convergence of both optic axes at a given objec is essential for single vision, is proved by the following curio experiment. If two small balls be placed near the further en of two tubes, it will be found, on looking through the tubes wi both eyes, that when the balls are brought nearer to the eye and these latter are made to converge, the two eyes recei the impression of a single ball. Each eye realises its ow image of one of the two balls; but the mind is conscious th

each image occupies a certain point in space, and these points being *felt*, through the muscular sense of the convergence, to coincide, we judge that one body only can occupy the same point of space at one time. From this experiment, it would seem, that single vision with the two eyes is not a simple sensation, but the result of experience, or of judgment, from facts presented to the visual and muscular senses.

Such being the conditions as to the position of the two eyeballs, necessary to single vision, various theories have been advanced, to account for the actual *combination by the mind*, of the two images. By some, this is thought to be dependent on a fixed structural condition, such as a peculiar arrangement of the fibres of the optic nerves, which decussate at the optic commissure, and are supposed thus to bring certain parts of the two retinæ into identical or corresponding relations, as regards the sensorium. The right halves of the two retinæ, are supposed to be connected, by the fibres of the two optic nerves, with the right optic sensorial nervous centres, and the left halves of the retinæ, in like manner, with the left optic centres, this arrangement being effected by a supposed semi-decussation of the fibres of each optic nerve. If such an arrangement existed, each optic sensorial centre would obviously receive impressions belonging only to the same side of the field of vision. It is probable, however, that the decussation of the fibres of the optic nerves, is not thus partial, but almost, if not quite, complete; for amaurosis of one eye, or section, in animals, of one optic nerve, is followed by withering of the opposite optic tract only. Moreover, in any case, the sensorial impressions, being received by separate bilateral optic nervous centres, are, of course, themselves bilateral or double, and the necessity of explaining their subsequent combination by the mind, still remains.

The actual combination of the two impressions, like the combination of those of hearing, smell, and taste, must, however, be the result of some mental operation, either intuitive, experimental, or rational. There is no doubt that the convergence of the two eyes to a fixed point in the object, is a necessary condition of seeing it single; and of this convergence, the mind certainly acquires, by experience, distinct cognizance, and hence refers both images to one object, as only one object can occupy the same point in space. In certain cases, as in squinting suddenly produced, double vision for a time occurs, but afterwards the mind neglects one or other

image; so, too, of the images of the same objects, which fall on non-corresponding points of the retinæ, one is either neglected, or becomes obscured by the stronger impression in the other eye. Doubtless, also, we are constantly neglecting double images formed, in the two eyes, of objects around the point of single vision.

It was shown by Müller, that when the eyes are fixed on a certain point, it is only those objects lying on a curved line, the chord of which is formed by the distance between the two eyes, or rather between the points of decussation of the luminous rays in the two eyes, which appear single. This curved line is named the *horopter* (Aguilonius), and its size and curvature are determined by three points, viz. the centres of the two eyes, and the points towards which the axes of these converge. By Helmholz, however, the horopter is shown to be usually a line of double curvature, formed by the meeting of two hyperbolic, or sometimes of two plane curves. Moreover, when the point of convergence of the eyes, is in the median plane of the head, and at an infinite distance, then the horopter is really a plane, parallel to the two visual lines, and corresponds with the ground on which we stand. In near vision, objects exactly in the horopter, are better seen stereoscopically, than those out of it, as may be illustrated by looking at a wire slightly bent, in its middle, towards the eyes, and held in front of the face, first out of, and then in, the line of the horopter, when it will be found that the bend in the wire, is most easily seen in the latter position. So also, in distant vision, the surface of the landscape, and the distance of its several points, are better estimated, because they lie in the plane of the horopter: for, if the head be turned aside, or inverted, our perception of those distances is less accurate.

In viewing an object situated beyond a certain distance the convergence of the visual axes is no longer necessary, and it has been calculated that these remain parallel for all objects the distance of which exceeds 120 feet. The angle formed by the lines of vision of the two eyes at the object, is called the *binocular parallax* of the object; for objects at a distance of 12 feet, this angle measures about 1°; it is, of course, regulated, for each individual, by the inter-ocular distance.

The objects which we have to examine in external nature are bodies having three dimensions, viz. length, breadth, and depth; in other words, they occupy *space*, and possess *solidity* however varied their shape, whether cubical, oblong, cylindri

cal, ovoid, or spherical, whether convex or concave, regular or irregular. In estimating the forms of such bodies with the aid of *one* eye only, we are guided by the ascertained correspondence of certain effects of light and shade with certain constant impressions derived from touch. Experience alone enables us to form complex notions, or judgments, of this kind. These correspondences are very liable to delusion, or misinterpretation; thus, if we look with one eye, at a raised cameo, or medal, illuminated from the right-hand side, we perceive that its surface is in relief; but, if by an effort of imagination, we suppose the light to come from the left-hand side, the design appears to be in *intaglio*, or hollow. The same effect may be produced by looking at the medal, through a convex lens held at a distance from the single eye, so that the image is reversed, the light still remaining on the right-hand side. These experiments show how completely the ultimate notions derived from our sense of sight, are mental.

But, in actual vision, we employ *both* eyes, each of which receives its own image of any given *solid* object. When such objects are within the range of the binocular parallax, the optic axes converge, and, moreover, the images or figures, formed in the two eyes, do not exactly agree; for each eye sees a different aspect of the same solid body, as, for example, of a sphere, a cube, or a book; the right eye seeing more of the right side, and the left, more of the left side, of the object. The difference between the two images, is regulated by the distance of the object, and by the interocular distance. We frequently, indeed, view an object, first with one eye, and then with the other, in order to gain a better knowledge of its form, or its position in space. By a mental combination of these two different perspective impressions, the idea of the solidity of the object is produced, not, however, as a simple sensation, or even as an intuition, but, in the very earliest period of our lives, as the result of a joint action of sight and touch, leading to the formation of a notion of solidity, as producing certain visual appearances of form, light, and shade. Such notions may seem to be intuitive in after life, and have been named *secondary intuitions*.

A good illustration of the effect of the two eyes in giving the notion of solidity, is furnished by the philosophical apparatus known as the *stereoscope*. By the combination, through optical means, of two drawings of a solid object, taken at

different points of view, and showing, therefore, two different aspects of the same, this instrument communicates to the mind, the appearance of a *solid* body, or of a body of three dimensions. The *reflecting* stereoscope invented by Wheatstone, consists of two mirrors, placed with their backs towards each other, at an angle of 90°; by means of two sliding frames, one at each side, two different perspective drawings of the same solid object, can be fixed and adjusted, so that their images in the mirrors, are separately seen by the two eyes, placed in front of the converging mirrors. The images thus formed in the two eyes, which resemble the natural images of the object, when this is regarded directly by them, are then mentally combined, as in the case of such natural images, into a single perception. But this only happens, when the eyes receive the images on the corresponding or identical parts of the two retinæ; for if either image is out of place, the two do not coalesce, but are seen separately, and *flat*, not solid. The *refracting* stereoscope, invented by Sir David Brewster, consists of two eccentric double convex lenses, each connected with a sliding tube, by which they can be adjusted to suit the sight and the distance between the two eyes of the individual. Proper perspective outlines of bodies, when viewed through this stereoscope, convey to the mind the idea of solidity. The action of the mind in producing these results, is shown by the fact, that two pictures of similar objects, differing slightly in size from each other, convey to it the idea of an object intermediate in size. Such a combination probably often occurs in ordinary vision; for many retinal images of the same object, must be of unequal size in the two eyes, as, for example, those of near objects placed at different distances, and in different directions, as regards each eye; so likewise, in the case of persons, in whom the two eyes have different focal distances, the two images of a given object must be of different dimensions. But objects at a great distance, those lying opposite the middle of the eye, and those at equal distances from the median plane of the visual field, produce images of equal size. When totally different pictures are viewed in the stereoscope, as, for example, a man and a horse, the impressions produced are various; sometimes the two pictures are blended and confused, sometimes they are seen alternately, and sometimes one is neglected, and the other only seen. The brighter picture usually predominates. In the *stereomonoscope* of Claudet, the separate images of a solid object, are combined, by means of two lenses, on the same

part of a screen of ground glass, when, by their coalescence, they produce, in the eye of the observer the stereoscopic effect.

Wheatstone has contrived another instrument, named the *pseudoscope*, which, by diminishing, or increasing, the angles at which the rays of light from an object ordinarily enter the eye, reverses the visual relations between the near and distant points of an image. A concave body appears convex, a convex body, concave; a bust, seen from the front, presents the appearance of a deep hollow mask, whilst the interior of a mask looks like a prominent cast. These phenomena are known as *conversions of relief*; they also prove the influence of the mind, in the ultimate interpretation of visual effects.

When we view distant objects, beyond the range of the binocular parallax, the appearances of solidity and relief, and our conclusions concerning these, are arrived at indirectly, or by processes of judgment and experience, in the same manner as when one eye alone is used. Persons who have lost one eye in infancy, must acquire their notions of the solidity of objects, by the conjoined use of touch and sight, aided by movements of the head or body.

The retina conveys to us a distinct sense of *locality*, dependent on the stimulation of two or more points of its surface; and these impressions, projected outwards in the field of vision, furnish us with the means of recognising *intervals* of *space*. The two first dimensions of space, viz. length and breadth, like those of a solid body, are easily recognised, even by *one* eye, according to the angles formed by the different lines of visual direction; but the third dimension of space, viz. that of depth, is more difficult of appreciation, and requires the use of *both* eyes.

Our estimation of the linear *direction* of external objects, and of their relative, or angular, distances from each other, upwards, downwards, sideways, or obliquely, i. e. of their apparent *position*, can be formed by one eye alone; but for the appreciation of their real position, it is necessary to be able to judge of their *distance* behind one another, or their depth in space. In the case of near objects, we, to a certain degree, estimate their depth in space, in the same manner as we judge of their solidity, by means of a stereoscopic action of both eyes. In this way, we become conscious of the intervention of a certain depth of space between near objects; but in order to estimate more accurately, their relative distance behind each other, it is supposed that we are able, by

looking from one object to another, to obtain important data from the muscular movements by which the two eyes are made to converge, and probably also from the changes which ensue in their focal adjustment; this is especially the case in regard to near objects, in looking at which, these actions require a greater effort. The knowledge thus obtained is not a mere sensation, but a mental notion, founded on the judgment, and helped by experience. Infants are entirely unable to judge of distances.

In estimating the real positions of distant objects, beyond the range of the binocular parallax, however, there is no convergence of the eyes, and frequently no focal adjustment is required; here, we are guided by movements of the head, by the effects of different distances on the apparent size of objects, such as are explained by linear and plane perspective; by the changes in the distinctness of outline, shadow, detail, and colour, due to aërial perspective; by the manner in which objects intercept, or are intercepted by, each other; by comparison with known objects, and, if these are in motion, by their absolute and relative rates of movement. It is by the perception of objects in space, that we obtain, through the eye, as well as through touch, materials for the mental conception of space itself.

An inexact estimate of relative distances, leads to certain errors as regards the sizes of objects. Thus, the idea that the sky at the horizon, is more distant than the sky directly above us, an idea dependent on the number of known and near objects between us and the horizon, leads to an erroneous estimate of the size of the rising or setting sun or moon, which thus appear to us larger than when they are seen above our heads. According to another view, the image of the sun or moon, seen near the horizon, is compared, by the mind, with the smaller images of intervening distant objects known to be of great size, and so those luminaries are interpreted to be of larger dimensions than when seen in the open sky. Through a telescope, these bodies appear nearer than they are, and hence the magnifying effect is underrated by the observer. Convergence of the eyes, also influences our judgment of distance; for, and this is remarkable, a fixed object appears smaller, when the optic axes are made to converge in front of it. In railway travelling, objects passed near the side of the road, appear larger, and nearer, than they are, because their rapid movement past each other, suggests, as we shall see,

large *angular motion*, and therefore unreal proximity. Objects seen through a fog, seem larger than they are, because their indistinctness suggests the notion of great distance.

We are only able directly to perceive the *movements* of objects, when these take place in a direction *across* the field of vision, in which case, the image of the moving object has a motion across the retina, and hence the motion is perceptible. Movements in the direction of the line of vision, i. e. from, or towards, the centre of the eye, are not immediately perceived, the image, as a whole, having no motion across the retina, although its dimensions undergo increase or diminution, according as it is approaching or receding. The *apparent movement* of an object, from one point in the field of vision to another, depends either on the motion of the image upon the retina, or on the motion of the latter in regard to the image. The extent of this motion, is measured by the angle formed in the eye, by two lines drawn through the eyeball, the one from the point whence the object moves, the other from the point where it is arrested; hence the movement is termed the *angular motion* of the object. This motion may be too slow to be easily observed; and, on the other hand, unless the perception of a moving body be sufficiently prolonged in time, it appears to stand still; as when a rapidly moving body is instantaneously illuminated by an electric flash; or as when the capillary circulation in the web of the frog's foot, is momentarily looked at under the microscope.

We judge of the *real motion* of objects from point to point in space, when these are within the range of the binocular parallax, by a stereoscopic use of both eyes; in estimating the actual direction and extent of the motion, we are assisted by those changes in the convergence and adjustment of the eyes, which are essential to keep the moving object in sight. Moreover, changes in size, distinctness of outline, and colour, and the passage of the moving body before or behind others, assist us in the formation of a judgment. In the case of objects beyond the range of the binocular parallax, these latter are the only data on which we base our conclusions.

It has been remarked, that when a given object approaches, or recedes from, us, the estimate formed by the mind of its real size, does not become confused or altered. It must, however, be added, that this is only true of objects moving at a moderate rate; for certainly, as any one may find by expe-

rience, a locomotive engine, advancing rapidly towards the eyes, on a straight piece of railroad, appears to swell out, or, as it were, to *grow*. The movement is here too rapid for the eye or mind not to be deceived. The explanation offered of the accuracy of our perceptions under ordinary circumstances, is, that, whilst, the increase of size in the retinal image of an approaching object, suggests an increase in its dimensions, yet the convergence of the two eyes necessary for the distinct vision of the object, is accompanied by a reduction of its apparent magnitude. The two effects, therefore, counteract each other. In the case of a receding object, the opposite conditions occur.

The movements of the eye itself, are accompanied by movements of the retina, as it were, *behind*, or *through*, the images of the various objects in the visual field; if the eyeballs be rapidly moved, these objects appear to acquire a general motion. There is, however, no apparent motion of the objects in regard to each other, for the relative position of their images, remains unaltered. When we are carried through space in one direction, as in railway travelling, objects appear to move in the opposite direction, and near objects appear to pass us relatively faster than more distant ones, for the angular motion of objects is greater, the closer their proximity to the eye. This assists us in judging of the rapidity and uniformity of our own movement, as well as of the distance of objects. If we look intently at certain objects in motion, after a time they seem to be at rest, and ourselves appear to be in motion; thus, on watching a running stream from a bridge over it, the stream soon appears to be still, whilst we seem to be moving with the bridge, in the opposite direction.

Such being the modes in which sight is employed for the purpose of informing us of the presence, size, shape, position, and movements of external objects, there yet remain many phenomena of vision which require to be considered.

For the stimulus of light to produce an impression upon the retina, it is essential that the portion of its surface acted upon by the luminous rays, be of a certain size, that these rays be of a certain strength, and that the retina be exposed to their action for a certain period of time. Images of luminous objects of a certain magnitude, might be regarded as mosaic patterns, composed of an infinite number of minute luminous points; theoretically, these are infinitely smaller than the ends

of the retinal rods. It has been calculated that a body, the image of which occupies only $\frac{1}{34500}$th of an inch of the retina, is visible to the eye, which is considerably less than the diameter of a single retinal rod or cone. It is said, however, that two impressions are distinctly or separately perceived, only when a certain distance intervenes between them; this is said to correspond with the diameter of the cones. White bodies on a black surface, or black bodies on a white surface, which measure as little as $\frac{1}{400}$th of an inch in diameter, can be seen by the naked eye; bodies still smaller can be perceived, if the attention be fixed, and the light powerful, though their outline becomes indistinct; but if less than $\frac{1}{540}$th of an inch in diameter, they are no longer visible, although they can still be seen when arranged in rows. Lines, such as opaque threads, are visible, even when only $\frac{1}{4900}$th of an inch in thickness. Bright bodies of exceedingly small size are visible, which, were they less brilliant, would be invisible. If the light be not of a certain intensity, the retina is not roused to vision; the appearance of darkness, in this case, is dependent, not on a total absence of light, for it is still present, but on its want of intensity. When an opaque body passes before the eyes with great velocity, the period of time during which it is visible, is so brief, that the retina receives no impression of the object; hence cannon-balls are invisible when they pass before us, but not always, when they approach or recede from us. Luminous bodies, on the other hand, however rapid their course, and whatever their direction, are always visible.

Luminous rays from a small object, falling on the retina, not only excite impressions in that portion of the retina which receives them, but also in the surrounding surface for a certain distance. The stimulation of the retina by the luminous rays, is, it would seem, diffused over the portions of the membrane contiguous to that directly exposed to the action of the stimulus. This diffusion of luminous impressions is known as *irradiation.* The phenomenon is particularly observed in looking at bright objects on a darker ground. It is owing to irradiation, that minute white objects painted on a black ground, not only appear much larger, but are visible at greater distances than natural; whilst, on the other hand, dark objects of the same size on a white ground, appear smaller, and sooner become invisible at a distance. A narrow bright strip of paper seems wider than a dark one of equal size. The larger apparent size

of the stars, as the sky becomes darker, and the peculiar appearance noticed in the new moon, viz. that its light crescent seems to belong to a larger sphere than the feebly illuminated portion of its surface, are also due to irradiation. In certain cases, the increased size, or blurred image, of a luminous object, is owing to defective accommodation of the eye, and to dissipation of the luminous rays.

Impressions made upon the retina have a certain *duration.* They continue to be perceived during a much longer interval than the impressions which produced them, and their persistence is greater, the greater the persistence of the original impressions. They are of the nature of after-sensations, or the so-called *spectra*, and have been named the *primary* or *positive after-images.* They last generally about $\frac{1}{50}$th of a second, but may endure for $\frac{1}{2}$ a second. Their average duration is about $\frac{1}{8}$th of a second (Plateau). Were it not for the duration of impressions, vision would not be continuous, for in every act of winking, all surrounding objects would be lost sight of. Impressions, occurring at shorter intervals of time than those just mentioned, are not perceived as distinct or separate. It is owing to the duration of the sensation, that after looking at a vivid light or a bright colour, if the eyes be closed, or the head be suddenly turned away, the impression continues for a certain period. The effects of different colours presented, in rapid succession, to the eye, as illustrated in experiments with the *colour-top*, which is a spinning-top painted in differently-coloured segments, also depend on the duration of retinal impressions. Various secondary or tertiary colours, and even a tolerably pure white, are produced by the rapid rotation of differently-coloured tops. The appearance of a complete circle of light, which is seen on rapidly whirling round a stick lighted at one end, the curved lines of fire seen in a lighted 'Catherine wheel,' and the indistinct haze caused by the rapid revolutions of the spokes or other parts of a wheel, are explained in the same manner. If a small piece of cardboard, on one side of which there is painted a bird, and on the other a cage, be made to revolve rapidly by twisting strings fixed to each end, the bird appears to be in the cage. The toy known as a *thaumatrope* or *stroboscope*, consists of a disc, on which are painted sets of figures of men or animals, in the different positions of some act, as, of leaping, running, or tossing balls ; when it is made to revolve, and the figures are looked at through a slit, they are combined into one image, which appears to be

in motion. When two exactly similar toothed wheels, placed one in front of the other, are made to revolve, in the same direction, and at the same rate, the image appears stationary; but if the number of teeth, or the rate of velocity, differs in the two wheels, then a revolving image is seen (Faraday). After looking, for any length of time, at objects in motion, the appearance of movement may be communicated even to stationary objects; thus, after having been on the sea, all surrounding objects appear, for a time, as if they were in a state of constant upward and downward movement.

When the retina has been previously in a state of repose, especially in cases of prolonged residence in the dark, the influence of any given quantity of light, as well as the rapidity of its action, and the duration of its impressions on the eye, are much greater than when it has previously been in a state of activity. If the intensity of the light be very great, the painful effect called *dazzling*, is produced, and the nervous power of the retina may be permanently destroyed, as, for example, when a flash of lightning suddenly annihilates vision. On the other hand, blindness may result from the continuance of the opposite condition; for if the eye be deprived of sufficient light, for a very lengthened period, blindness will ensue from want of exercise of the retina. If the eye, previously in a state of rest, be suddenly exposed to a bright light, the rays impinging upon the retina through the dilated pupil, are painful to the eye, and vision is confused, till the pupil, having had time to contract, a large number of the rays are excluded, and the retina itself, moreover, becomes accustomed to the excess of light. When a sudden transition takes place from light to darkness, opposite changes of course ensue.

The relative intensity of light, is measurable by means of instruments called *photometers*, the action of which is, however, entirely dependent on the discriminating power of the eye itself, through the comparison of shadows of different strengths. We have no means of estimating the absolute quantity or intensity of light. It is possible to read with both eyes, during twilight, when the employment of one eye would be useless; and, moreover, a brilliant light dazzles, or blinds, the two eyes, more rapidly than it does one. At the same time, no difference of brightness is ordinarily observable, whether we look with one eye or with both; for on closing one eye, the pupil of that eye dilates, and, consentaneously, that of the other, so that more light is admitted to the open eye.

There are many interesting points connected with the so-called *secondary*, or *negative*, *ocular spectra*, which are distinguished from the primary or positive spectra, by not resembling the original impression. If, after looking at dark, white, or luminous objects, the eyes be covered, so as altogether to exclude the entry of light, images of these objects, or impressions related to such images, the results of *after-sensations*, remain upon the retina, and these are named negative spectra. In the case just mentioned, of closing the eye, the spectra are dark, white, or luminous, like the original causes of the visual impressions. But if the eyes, after looking steadily at a white object or spot, on a dark ground, instead of being closed, be turned towards a white surface, the spectrum perceived is black. If the condition of things be reversed, the spot being black, and the ground white, the after-image left is white. This difference in the appearance of the spectrum, as compared with the object, is thus explained. In the first experiment, the portion of the retina on which the image of the white spot has been received, being exhausted, is less susceptible of the action of a given quantity of light, than the surrounding unexhausted portion which corresponded to the black ground, and, therefore, though receiving white light, it is less acted on by it, than the rest of the retina. On the other hand, in the second experiment, the portion of the retina which has received the image of the black spot, is unexhausted, and is therefore more susceptible than the rest, of the action of a given quantity of light. For the same reasons, the spectrum, produced by gazing at the sun, and then turning the eyes from it, is dark, if the eyes be turned towards a white surface, though it is luminous, if the eyes be closed, or directed towards a dark surface. The spectra, which result from the impressions of colourless objects, are, as a rule, themselves colourless. But when luminous rays of great intensity fall upon the retina, different phenomena ensue. Thus if the eyes be turned towards the sun when shining brightly, and then be covered, the spectrum, at first, is of the same colour as the sun itself, but rapidly assumes different colours in regular succession, before it vanishes; it first becomes yellow, then orange, red, green, violet, and black. When the eyes, instead of being covered, are turned towards a white surface, the after-image passes through the same series of colours, the order, however, being reversed. In any case, these colours are due to certain states of the retina, and are called *subjective*, *acci-*

dental, or *physiological colours*. The spectra thus formed, move with the eyes; their size increases with the distance of the surface on which they are projected; their vividness and duration are proportional to the strength and duration of the primary impression; and they fade away gradually, with successive changes of colour. These after-images are weaker in the sides of the eyes, than in the centres or points of distinct vision; they may be produced by objects to which the attention has not been directed; and there are persons who have a singular power of retaining or reviving them.

The most remarkable spectra are those produced by the impressions of distinctly-coloured objects. The colour of the spectrum, in these cases, is always complementary to that of the object; thus, if after looking steadily at a red object, the eye be turned on to a sheet of white paper, the spectrum is green; the spectrum of a green object, in the same manner, is red; that of a blue object, is orange. The explanation of this, is, that the retina is so exhausted as regards the colour first looked at, that it is no longer so readily excited by the corresponding coloured rays of the white light, which pass from the surface of the paper, but only by the complementary rays. After looking at a given colour, and then turning the eye to the complementary colour, the latter appears brighter and more intense than natural. Primary colours are more exciting to the retina than secondary and tertiary colours; and of the three primary colours, red is the most exciting, and blue the least so. Contrasted colours, and contrasts of light and shade, heighten their separate effects. Thus, the depth of shadows is always greater, in proportion to the intensity of the light which produces them. Grey spots, occupying a white surface, present a darker appearance than a grey ground of the same tint. The production of the physiological colours by contrast, as just mentioned, is a further example of this class of phenomena. A strip of grey paper placed on a bright coloured field, presents a faint tint of the colour which is the opposite of that of the surface on which it lies; on a red surface, it frequently has a greenish tint; on a green surface, a reddish tint, and so on. Such phenomena are only produced, when the surface of the field is of a very bright colour, and when the portion of the retina exposed to the action of the new colour, is in a state of relative repose (Müller).

When, by means of the stereoscope, two different colours are thrown upon corresponding points of the retina, the impres-

sions sometimes alternate; sometimes one colour preponderates; at other times one colour appears in one part of the visual field, and the other in the other part; and, lastly, the two colours may be blended into a mixed or compound colour. These curious experiments prove that the impressions are more or less blended in the sensorium. The blended colours are usually very bright. On looking with one eye through a coloured glass at the sky, and keeping the other eye closed or looking with it at the sky without a glass, it is found, that in the former eye, there arise spectra of the *complementary* colour to that of the glass, in the latter, spectra of the *same* colour as that of the coloured glass. The former eye is sufficiently excited to produce secondary or negative spectra, whilst the latter, less perfectly stimulated, but still affected through the colour in the other eye, only produces positive spectra.

Irritation or congestion of the retina, altered conditions of the optic sensorium, diseases of the brain, dreams, and peculiar mental states, give rise to various kinds of spectral phenomena. Bodies seated in, or on, the eye, also produce appearances in the field of vision, called *entoptical* images, such as *moats*, or *muscæ*. Thus, fixed particles of blood, lymph, or pigment, on the retina, or others in the lens, such as radiated streaks or spots, cause *fixed muscæ*; and movable particles, on the surface of the cornea, such as tears or mucus, in the aqueous humour, or in a softened vitreous humour, cause *muscæ volitantes*, or *flying muscæ*. They are of various forms, some looking like spots or streaks, others assuming a hair- or bead-like shape.

Such of these entoptical images as are caused by objects in front of the retina, are named *extra-retinal*. They are not usually noticed, because light passes behind the little objects, which would otherwise cast a shadow on the retina; but by admitting the light into the eye, through a minute hole in a card, so that the retina receives rays from one direction only, distinct shadows of such objects are cast on the retina, and produce the entoptical images. If the orifice in the card be in the principal anterior focus of the eye, that is, about half an inch in front of it, the entering luminous rays become parallel behind the lens, and the images are of the same size as the object; if the card is nearer the eye, the rays diverge, and the shadows are larger; if it is moved further off, the rays converge, and the images are smaller. The *intra-retinal* images include those of the bloodvessels, and the blood moving in

them, described by Purkinje, who showed, by means of a simple experiment, that most persons are able to see the shadows of their retinal bloodvessels. The vascular image of the retina, or the *image of Purkinje*, is best perceived, by moving a lighted candle up and down, or in a circle, a few inches in front, and to one side, of the eye, so that the light may enter it obliquely, this being done in a dark room, or when the eye is directed towards a dark surface. The appearance of a bright field, moving with, and before, the eye, is then gradually excited; on it are seen dark arborescent vessels, branches of the central artery and vein of the retina, and even images of the optic eminence and yellow spot. The rods and cones of the retina are excited by the luminous rays, its general surface being thus illuminated; but the parts of its bacillary layer, which are covered by the vessels, being relatively more protected from the light, are perceived as dark arborescent ramifications, always much larger than the vessels themselves, since they are projected into the visual field. In accordance with the principles of visual direction, the appearances are, moreover, reversed, the optic eminence of the right eye being seen on the outer side of the yellow spot. The shadows of the vessels shift considerably, when the candle is moved about; and, as these vessels lie chiefly behind the nerve fibres, but in front of the rods and cones, it would certainly appear that the last-named parts are the recipient portions of the retinal structures. Another, and more striking, experiment consists in looking steadily at a uniform field of light, such as the sky, or an illuminated ground lamp-glass, and rapidly moving the finger, to and fro, in front of the eye. After a time, delicate reddish images of the retinal capillaries, and even of the blood corpuscles moving in them, are seen on the luminous field. This form of intra-retinal image has been made use of, to determine the velocity of the blood in the capillary vessels; it appears to be from $\frac{2}{100}$th to $\frac{3}{100}$th of an inch per second (Vierordt). Pressure will also produce entoptical images of the retinal vessels, and also of those of the choroid, shining on a silvery blue ground.

The dark field observed when the eyes are closed, or kept open in a perfectly dark room, is not absolutely black; it is often, from retinal excitement, covered with an obscure luminosity, and sometimes with minute points of light, like *luminous dust*. This field is not circular, but elliptical, like the ordinary visual field; it is projected into the exterior, moves with

the eyes, and is itself the result of a positive sensation, quite distinct from blindness. The size of this dark field diminishes in the horizontal direction, when the closed eyes are made to converge.

The curious spectra, named *phosphènes*, caused by pressure, with the finger, on the closed eye, have been previously mentioned, as well as the fact, that these luminous impressions are always referred to a direction opposite to that of the seat of pressure; pressure on the inner side of the eyeball, for example, excites a luminous spectrum which appears on the outer side. It was noticed by Müller, that pressure, with the finger, upon the eye, gives rise to a variety of luminous impressions, these being either annular, star-like, or square. But, according to Serre, the shape of these phosphènes is determined by that of the body which exercises the pressure, and by the extent to which the retina is acted upon by it. When the pressure is communicated by the finger, the spot is either roundish, or when the pressure is strong and widely spread, it is annular, forming a ring with a dark centre. When the pressure is made by a circular, triangular, or square object, the luminous figure is circular, triangular, or square, provided that the part compressed is entirely over the retina. But if the pressure be applied over the anterior margin of the retina, it gives rise to an incomplete figure, which becomes more so, the smaller the portion of the retina covered by the compressing body. A second spectrum is often perceived, in a direction corresponding with the point of pressure. This is produced by a change in the form of the coats of the eyeball, on the side opposite to the seat of the primary pressure; it is always a complete figure, because the retina itself is there continuous; such counter pressure acts on some portion of the deeper part of the eyeball. Lines connecting the primary and secondary phosphènes, or the points of the retinal surface by the stimulation of which these are produced, traverse a common centre of direction, which lies in the middle of the crystalline lens, and may be said to correspond with the visual centre of direction.

Light is the proper homologous stimulus of the retina, but various other, or heterologous, stimuli, such as irritation, blows, or pressure on the eyeball, or electrical shocks, excite luminous, and even coloured sensations or spectra of various kinds. Even the action of the orbicular muscles of the eyelids, or the sudden movement of the eyes from side to side,

will excite luminous impressions. Visual sensations, like all other sensations, may also be excited by internal stimuli. Thus, when the eyes are closed, and the retina is at rest, the field of vision is dark; but, if the optic nerve, or sensorial centre, is in a state of excitement, impressions of luminous rays, or of bright colours, are perceived. During congestion of the brain, each arterial pulse is accompanied by an alteration in the degree of light perceived by the eyes, owing to a pulsating illumination of the field of vision (Müller). Certain chemical agents, when absorbed into the circulation, also give rise to the sensation of light, either by producing some alteration in the condition of the retina, the effects of which are transmitted, through the fibres of the optic nerves, to the brain, or perhaps by affecting the nerve, or the sensorial centre itself. The action of opium, digitalis, and belladonna, in producing spectra, is well known, and the vivid and horrible spectral illusions seen in fever, and especially in delirium tremens, have often been described. Again, the motion of the blood is sometimes observed, especially after gazing at bright surfaces, such as the sky, or after looking for a certain time at a white surface. Indistinct movements in the luminous visual field, are then noticed. The appearance of dark bodies in rapid and constant motion, seen in cases of congestion of the brain, and also on suddenly rising from a stooping posture, are dependent on the movement of the blood, exciting luminous impressions. As elsewhere stated, no instance of the occurrence of these or other true spectra, where the two eyeballs have been removed, appears to have been recorded; so that it has not been proved, that such spectra can occur without the intervention of the retinal elements. Cases of disease of the retina, involving total blindness, are not quite satisfactory as evidence of this, for the retina may still be exceptionally excitable.

In many persons, the sensibility of the retina to colours, is remarkably acute, enabling them to discriminate between shades of the same colour, which, to other persons, present no difference. There are others whose sensibility to certain impressions of colour, is curiously defective. This affection, known as *achromatopsy*, *colour-blindness*, or *Daltonism*, consists in an inability to distinguish one colour from another. It is more common in the male than in the female, and is often hereditary. In some cases, it is limited to the lighter tertiary tints, which cannot be distinctly recognised; or there may be inability to distinguish some of the secondary colours; or the

insensibility of the eye to colours may be so great, that one o the primary colours, usually red, may not be recognised, con stituting *dichromism* (Herschel). Thus, bright red is, by som persons, indistinguishable from green; ripe fruit, such as cher ries, being, to them, of the same colour as the leaves. Lastly some individuals can only distinguish black, white, and grey

Insensibility of the eye to colours, is, sometimes a temporar affection dependent on internal causes, such as congestion o the brain, retina, or choroid, or it may be due to a derange condition of the digestive organs. As to the cause of colour blindness in general, nothing is known; it probably has it seat in the retina, perhaps in some deficiency in the structur or energy of the rods or cones; just as defects in the appre ciation of pitch and timbre, in the hearing of certain indi viduals, are supposed to depend on defects in the rods of Corti or of some of the other complex structures of the cochlea By some, however, the cause of this defect is believed to b in the sensorial nervous centre; it has also been suggested that it may be due to a peculiarity in the absorptive propert of some of the humours of the eye. Comparatively harmles in most persons, this defect may be of serious consequence i the case of railway guards, pointsmen, or sailors, who have t watch signals given by means of coloured lights.

It is by the forms and colours of the retinal images, that w judge visually of the forms and colours of the material world but the sense of sight is educated by experience, and by com parison with the results of the tactile sense, and thus, as w have seen, suggests to us complex notions. This fact is illus trated by the cases of persons born blind, who are said a first to imagine that the field of vision is flat, and even tha objects touch the eyes. The education of the eye, for distan vision in sailors, for the detection of minute objects by th microscopist, and for the appreciation of form, texture, an colour, in various commercial and manufacturing pursuits, a well as amongst artists, is well known. There is often a mental, as well as a visual, training in these persons. A acquired acuteness of vision may become hereditary, as woul seem to be the case in the Mongols and Hottentots. Th sense of sight is more liable to individual differences, and t illusions than any of the other senses.

Of the luminous rays which pass, through the pupil, on t the retina, a certain number are reflected by the choroid

the retina, and the transparent media of the eye. Some of these reflected rays impinge on the posterior surface of the iris, and are there absorbed by the uvea; this structure also absorbs certain rays, passing from the borders of the lens, which would otherwise confuse and dazzle the retina. Some of the rays reflected from the bottom of the eye, however, pass out through the pupil, and converge to a focus; these are few in number, and do not, when the eye is ordinarily examined, afford information as to the condition of the deeper ocular structures. But light may be thrown into the eye in such quantity, that, when reflected from its deep parts, it furnishes us with this information; and, an ingenious instrument, named the *ophthalmoscope*, has been invented, by means of which the interior of the eye can be easily seen. It consists of a circular, slightly concave, mirror, having a focus of about ten inches, perforated in the centre by a small aperture, and fixed in a handle. The pupil of the eye to be examined, is previously dilated by the introduction of a few drops of a solution of atropine between the eyelids, and the examination is made in a darkened room. A lamp is placed close to, and on a level with, the eye to be examined, care being taken, that none of its rays fall directly on the eye. The observer sits near to, and facing, the eye, and holding the mirror steadily in one hand, brings the rays from the lamp to a focus on the retina; he then takes a convex lens, having a focal length of from two and a half to three inches, in the other hand, and holds it about two and a half inches in front of the cornea. The anterior parts of the eye, can be generally examined without the aid of the lens; by its use, however, the optic eminence, the yellow spot with its elevated rim, and the arborescent vessels of the retina, can be distinctly seen, but in an inversed position; the retina, as thus examined, appears to be of a shining red colour. In the healthy condition, the crystalline lens is invisible. Various diseased states of this and the deeper structures, are, however, easily distinguishable by the aid of this useful instrument.

The Organs and Function of Sight in Animals.

The general structure of the eyeball, and the uses of its several coats and humours, are similar in all the Vertebrata, and correspond with the structure and functions of the same parts in Man. But many modifications in these organs, are observed in the several vertebrate

classes. In Mammalia, there are noticed, in the first place, remarkable differences in the size of the eyeballs, which, as a general rule, are larger in proportion to the powers of vision, in any given animal. Some species of nocturnal habits, have very large eyes, as noticed in the lemur, dormouse, aye-aye, &c.

The Carnivora generally, have eyes of moderate size; in the seals, the coats of the eyeball are strengthened, to enable it to resist the pressure experienced during submergence. In the insectivorous Cheiroptera, the eyes are usually small, except in some nocturnal species. In the mole, which lives habitually in darkness, the eyeball is so extremely minute, that even its existence has been denied; it possesses, however, the usual parts, and is supplied by a branch of the fifth cranial nerve; the optic nerve is said to be absent, although the optic tracts and commissures exist. Amongst the Pachydermata, the eyes are small. In the Cetacea, the thickness of the coats of the eyeball, especially at its hinder part, is enormous, in order to preserve its shape, under the pressure of different and extreme depths of water.

The eyeballs are of great relative size in the Ruminants and the Solipeds; they are generally far apart, and very prominent. In the camel and giraffe, their position is so lateral and projecting, that those quadrupeds can look backwards, without turning their heads. The usual direction of the antero-posterior axes of the eyeballs in Mammalia, is obliquely forwards and outwards; but in the Quadrumana, the eyes are directed forwards, as in man; whilst in the Rodentia, the direction of the axes of the two eyes, is completely lateral.

In such cases, the relation between the parts of the retina, must be peculiar. The images of objects, seen in *front* of the animal, must fall, not as in man, on the outer half of one retina, and on the inner half of the other, but on the outer halves of both retinæ, and on identical points of the two retinæ, occupying inverse positions as regards the axes of the eyes. Objects placed directly to either *side*, must be seen independently in the corresponding eye, and the points of the retinæ on which they are received, can have no correspondence or identity with each other; otherwise, two similar objects, seen, one on the right, and the other on the left, hand, would be combined, and appear as one object. It is not yet known whether the decussation of the optic nerves, presents peculiarities, in accordance with the special seats of the identical points of the retinæ in these animals, and with the absence of identity in other parts of the retinæ.

In certain Mammalia, the orbital fascia or membrane, which completes the orbit, contains plain muscular fibres, and when the sympathetic nerve is irritated, it contracts, and presses the eyeball forwards. In the Mammalia generally, the third eyelid, or membrana nictitans, is well developed; in the elephant, it is provided with two special muscles, and has a very strong fibro-cartilage imbedded in it. In the Ruminants, the third eyelid is provided with a large gland, named the *Harderian* gland, the mucous secretion of which, facilitates the motion of that membrane over the eyeball. In the Sirenia, amongst Cetacea, the eyelids are represented only by a border of loose skin, the margins of which are provided with small mucous glands; a membrana nictitans is present; in the Cetacea proper, this is the only structure which supplies the place

f the eyelids. No lachrymal gland exists in the Cetacea. This gland, however, is very large and lobulated in all the Ruminantia. In the deer, and in some antelopes, the so-called *tear-pits*, formed by recesses in the lachrymal bones, between the orbit and nose, are met with; they are lined by an extension of the integuments, and open externally by a gutter-like aperture.

The muscles of the eyeball in almost all Mammalia, resemble those of man; but, except in the Quadrumana, there generally exists a seventh ocular muscle called the *retractor oculi*, or *choanoid muscle*, interposed between the recti muscles and the optic nerve. In seals, the crystalline lens is more nearly spherical than in other Mammalia, in accordance with the requirements for the production of distinct images under water, as will be mentioned in speaking of the eyes of fishes. In the castor-beaver, the cornea is likewise flattened, and the lens nearly globular, to suit its aquatic habits. The vitreous humour in the Cetacea, is much flattened from before backwards; the cornea is also flat, but the crystalline lens is, as in seals, nearly spherical. In the Ornithorhynchus, a cartilaginous plate, projecting from the orbit, protects the eye above; the sclerotic coat is also cartilaginous, the cornea is flat, and the lens small.

In many Mammalia, the bottom of the eyeball is partially lined by a membrane, called the *tapetum*, which presents different brilliant hues; it consists of a layer of thin fibres, or, as in Carnivora, of nucleated cells, of metallic brilliancy; this reflects the rays of light from the bottom of the eye, like a concave mirror, and causes a luminous appearance in the eyes of those animals in the dark. In Ruminants, Solipeds, and Pachyderms, the tapetum presents a greenish blue metallic lustre; in most Carnivora, it has a silvery hue, excepting in the cat, in which it is green; sometimes it resembles mother-of-pearl. The Quadrumana, Edentata, and Monotremata, like man, have no tapetum. The shape of the pupil also presents peculiarities in certain Mammalia; thus, in the cat it is elliptical, and even linear, in a perpendicular direction, when contracted under a strong light. Solipeds and Ruminants have a transversely oblong pupil. It is remarkable that the yellow retinal spot is, as a rule, absent in Mammalia, the only exceptions being in the Quadrumana.

In Birds, the eyelids are well developed, and, except in owls and a few others, the lower lid is generally more movable than the upper one; contrary to what occurs in Mammalia, it covers the larger part of the eyeball, and is even provided with a special depressor muscle. The third eyelid, or membrana nictitans, is always present, and fully developed; in birds of prey, it is in constant use, serving to cleanse the eyeball, or to temporarily diminish the glare of bright sunlight; it is sometimes nearly transparent, but usually rather opaque. The nictitating membrane folds back on the side next the nose, by the action of its elastic tissue; but, for its projection over the front of the eyeball, two muscles are provided. Of these, one, named the *pyramidalis*, is a slender muscle, arising from the sclerotic, passing behind the back of the eyeball, curving over the optic nerve, and ending in a tendon, which slides through the border of the other muscle. This muscle, named the *quadratus*, descends from the upper part of the eyeball, and forms a muscular pulley for the tendon of the pyramidalis. After escaping from the pulley, this tendon continues over the back of the eyeball, and finds its

way to the lower border of the nictitating membrane. The contraction of the pyramidalis pulls the membrane across the eyeball; whilst the quadratus prevents the tendon of the muscle from straightening itself, and so coming down upon the optic nerve. Birds have, in addition to the ordinary lachrymal gland, a large Harderian gland, situated behind the conjunctiva, at the nasal angle of the eyelids. The muscles of the eyeball are the same as in Mammalia; the superior oblique does not, however, pass through a pulley.

The eyeball of the bird, is very large in comparison with the size of the head and brain, especially in the nocturnal birds of prey. It is not usually so spherical as in Mammalia, but is sometimes somewhat flattened, and, in the larger raptorial birds, is often lengthened by the prolongation of the anterior part of the sclerotic, and by the extremely convex form of the cornea. Movable bony plates, situated in the sclerotic, frequently preserve this elongated form, an arrangement also found in certain reptiles and fishes, though in them, the eyeball is flattened. The choroid coat in birds generally, sends forwards into the vitreous humour, from near the entrance of the optic nerve, a remarkable plicated vascular membrane, named the *pecten*, or *marsupium*. This is falciform, or irregularly quadrangular in shape; its plicæ, or folds, are, in some species, only four, but, in others, nearly thirty in number. The pecten sometimes reaches the posterior part of the capsule of the lens. It is not muscular, but is supposed, by means of changes in the state of distension of its vessels, to alter, either directly or indirectly through the vitreous humour, the position of the lens in the interior of the eyeball, and to assist in adjusting the focal distance of the eye. The action of the pecten, which varies in size and shape in different birds, is, however, not well understood. The Apteryx australis is the only bird in which the pecten is absent. The iris is usually very active, and contains striated, as well as unstriped, muscular fibres; its movements are more active and rapid than in other animals, in which it contains only plain muscular fibres; and, in some birds, it is said to be even under the influence of the will; its colour varies, but it never exhibits a metallic lustre. The pupil is generally round, though it is lengthened vertically in the owl, and horizontally in the dove and goose. The internal ciliary muscle also exists, and doubtless influences the form and position of the lens; whilst the muscular fibres around the circumference of the cornea (Crampton), and even the proper muscles of the eyeball, may, by compressing its movable osseous plates, alter the relative convexity of the cornea, and so assist in focussing the images of objects upon the retina, however variable their distance. The power of adjusting the eye to accurate vision at different distances, exists in much greater perfection in birds than in any other animals. Vultures, e. g., fly at great altitudes, and yet discern their peculiar food; and other birds of prey, which, in their rapid flight, diminish so suddenly the distance between them and the objects of their pursuit, afford a further illustration of this wonderful power of adjustment. The crystalline lens is flattish, especially in vultures, which are so long-sighted; but it is rounder in owls, which are extremely near sighted; it also becomes progressively more spherical in aquatic birds, according to their subaqueous habits, being less so in cormorants, more so in ducks, and still more so in divers.

Amongst Reptiles, serpents are destitute of eyelids, the skin being continued over the cornea. In crocodiles, tortoises, and turtles, the two eyelids are well developed, but there are no eyelashes. In the cameleon, the skin forming the eyelids, is united into a circular zone with a central aperture. The membrana nictitans and the Harderian gland, when present, are both of large size. The lachrymal apparatus exists in all cases: the lachrymal gland is very large in the turtle. In the Chelonian reptiles, the sclerotic contains a cartilaginous or bony ring. The pupil in the crocodile and many Ophidia, is elongated vertically: it is, however, frequently round, and sometimes of a rhomboidal figure. There is sometimes a rudimentary pecten. In the Aquatic species, the cornea is flattened, and the lens of a globular shape; but in the terrestrial species, the lens is flatter: in Emys, it appears elliptical. When the lens is not globular, the cornea is more prominent.

The Amphibia are provided with eyelids, and the membrana nictitans is moved by its own muscles. The lachrymal apparatus is absent. In the frog, there are only three recti muscles; the oblique are absent: but there is a transverse muscle, which passes directly under the eyeball, and is attached to each side of the orbit. The sclerotic is cartilaginous, the choroid well developed, the iris is said to be motionless, the cornea flat, and the lens spheroidal.

In Fishes generally, the integument passes over the eyes, forming a transparent covering; there are neither eyelids, nor lachrymal apparatus, the medium in which these animals live, maintaining the cornea moist and clean: but in the sunfish, and in a few species of sharks, there are eyelids, and, it is said, in the latter, even a membrana nictitans. The eyes are usually of large size, especially in those fish which live at the bottom of the ocean; they are smallest in those which burrow in the mud. In the Amphioxus, there are two dark spots, on which, according to Vogt, a hemispherical lens is found immediately beneath the integument. The eyeballs of fishes are lodged in very large, cartilaginous, or bony, sockets, and are usually provided with four recti and two oblique muscles; they are symmetrically placed on the sides of the head, their usual direction being outwards, but sometimes upwards; in the flat-fishes, owing to the peculiar conformation of the cranium, both eyes are situated on the same aspect of the head. In fishes generally, the eyes are so completely lateral, that the visual field of each must be almost or entirely independent; and it is remarkable that in these animals, there is no optic commissure, the optic nerves being entirely unconnected, and completely decussating, one optic nerve passing over into the opposite optic tract. In the Amphibia, Reptiles, and Birds, the optic nerves, as in the Mammalia, are more or less blended at the optic commissure.

It may here be mentioned, that the decussation of the optic nerves in the Vertebrata, an arrangement which, not having been met with, even in the highest Mollusca or Annulosa, may be typical of the Vertebrate organisation, seems to be related to the decussation of the motor tracts in the medulla oblongata, which is likewise quite peculiar to the Vertebrate type of structure, not occurring in the Annulose or Molluscous animals. The constant use and importance of sight, in the government of the movements of animals, probably necessitates a co-ordination between the visual and motor organs on the two sides of the body; but why this cross-action should prevail in Vertebrata, and not in the non-Vertebrata,

has not been hitherto explained. A suggestion may here be offered, viz. that it depends upon the inversion of the retinal images within the eyes of the Vertebrata, necessitated by the optical structure of their eyeballs, and by the concave recipient surface of the retina. In the non-Vertebrate Annulosa, e.g. the eyes are convex, and images of surrounding objects, and also of the limbs and other appendages of the animal, are received in a true, and not in a reversed as well as an inverted, position: those on the right-hand side of the animal, being received on the right-hand side of each eye, and those on the left, on the left-hand side, without inversion; in such animals, the motor apparatus is governed on its own side. In the Vertebrata, the right- and left-hand objects, and, therefore, the right and left limbs, are seen on the opposite sides of the eye; the guiding impressions thus perceived, pass over through the opposite side of the sensorium, and from thence, the motor stimulus again crosses the middle line in governing the movements of those limbs. In this way, the reversion of the visual impressions, necessitated by the structure of the eye, meets with a corrective action in the government of the limbs.

In the eyes of fishes, the sclerotic is very firm, and generally contains two cartilaginous plates; when, however, those are absent, the posterior fibrous part is of great thickness; in some fishes, indeed, the posterior part of the coat is one inch and a half thick; in certain large fishes, it forms even a bony cup, into which the cornea is fitted in front, and through an opening in which, the optic nerve enters behind. By this great strength of the sclerotic, which reminds one of the similar provision in the whales, the sphericity of the posterior part of the eyeball is maintained. Sometimes a cartilaginous or tendinous pedicle connects the sclerotic with the bottom of the orbital cavity; in the skate, a distinct arthroidal articulation exists between the pedicle and the eyeball. The choroid coat is composed of several layers; the pigment, in the osseous fishes, has a silvery hue in its superficial fibrous layer, but is black or purple in its deeper layer; between these two layers, is a red horse-shoe shaped vascular organ, composed of tortuous blood-vessels, chiefly venous, and known as the *choroid gland*, the use of which is yet unexplained. Amongst the cartilaginous fishes, in the sharks and rays, the outer layer of the choroid pigment is of a dark colour, and the deeper one has a metallic lustre. In the sturgeon, and also in some osseous fishes, there exists a fold of the choroid, forming the falciform process, on which is often found a branch of a ciliary nerve, expanded at its extremity, and forming the *campanula* (Haller). The falciform process, like the pecten of birds, projects into the vitreous humour, and is fixed to the back part of the capsule of the lens. In the conger-eel, there are two such processes, by which the lens is suspended at two points. The iris, for the most part, presents a bright metallic lustre, and has a large, round, and slightly changeable, pupil; the pupil has, indeed, been described as being quite motionless. The anableps is said to have a double pupil in each eye; in the rays, a broad black velum is found in front of the pupil. After death, the form of the pupil in the fish's eye, is often very irregular. The retina usually reaches forwards to the border of the iris. It has been suggested, that fishes, living at a very great depth in lakes, or in the ocean, must be almost in a state of complete darkness; and that either their retinæ, with the plicæ upon the

falciform process, must be endowed with an increased sensibility to light, or that they possess in their barbules, or other appendages, sensory organs of touch which compensate them for their inability to see.

In those Vertebrata which live in the air, the refracting powers of the eye depend largely on the cornea and aqueous humour combined; but in fishes, the action of these parts must be comparatively slight, as their refractive power is so little in excess of water, the medium from which the light immediately enters the eye. The cornea, indeed, in fishes, is very flat, and the aqueous humour is very much reduced in quantity, conditions the very opposite of those found, for example, in the far-seeing birds of prey; but the formation of distinct images, by bringing the luminous rays to an exact focus on the retina, is accomplished chiefly by the crystalline lens, which is accordingly of very large size, relatively to that of the entire eyeball, completely spherical, and unusually dense, its internal laminæ being almost as hard as horn. These characters impart high refractive power to the lens in fishes; its focus is accordingly very short, and hence the vitreous humour, like the aqueous, is scanty, and its form flattened, so that the lens is closely approximated to the retina; in front, too, the lens usually projects through the pupil into the anterior chamber of the eyeball. In the Surinam sprat, the eyes are situated quite on the upper part of the head, so that they are often somewhat above the surface of the water; the pupil is partially divided, and the lens is also composed of two portions, so that it is supposed that one part of this curious eye is adapted for aërial, and the other for aquatic, vision. There have recently been described by Leuckart, minute lens-like bodies, found in the coloured spots upon the sides of the head and body of small fishes of the genera Stomias and Chauliodus; from the presence of these bodies, he regards the spots in question, as examples of true ocelli, or ocular spots; but this inference may be incorrect.

Amongst the Mollusca, the Cephalopods are remarkable for the great development of the eyes, which are larger than in any other non-vertebrate animals, and bear a closer resemblance to the organ of vision in the Vertebrata. The large spherical eyeballs, placed symmetrically on the sides of the head, are invested by a wide capsule formed by the integument, which is, at one part, transparent, and supplies the place of the cornea. This covering, however, is, not completely closed, but presents an opening through which the sea-water enters, and fills up the space between the eyeball proper and the capsule, so that there is no aqueous humour. In Loligopsis and others, this opening is of very large size, and the anterior portion of the lens projects freely into the sea-water. The lens lies deeply imbedded in the vitreous humour, and is divided into two unequal parts, one in front of the other, which are separated by a delicate interposed membrane, extending from the choroid. The anterior part is the smaller one. Each consists of a portion of a sphere, and their substance, though soft externally, is dense within, and contains a firm nucleus. The sphericity and density of the lens, suggest a resemblance to the lens of fishes, and are dependent on the same necessity of providing a refractive body of greater power than is needed in animals living in air. The double lens of the eye of a cuttlefish, is, indeed, an extreme example of such a provision. The choroid is of a dark colour, and there is a well-developed iris, with a kidney-shaped

pupil. By means of the ciliary processes, which are well developed, it is possible that the eye is accommodated to vision at different distances.

Amongst Pteropoda, the Clio has two eyes, which are placed behind the head, and somewhat resemble a bent cylinder. The Pulmo- and Branchio-gasteropods have, with but few exceptions, black points, or eyes, in the neighbourhood of the œsophageal ganglion, situated, either at the base of the tentacles, as in Limnæus, in the middle of those parts, as in Halyotis, or at the apex, as in the genus Helix or Snail. These simple eyes are dark-coloured elevations, covered by the soft skin of the tentacle, which constitutes a firm transparent cornea; behind this, is a globular lens, a cup-shaped choroid membrane, sometimes ending in an iris-like ring, and an optic nerve, expanding into retinal elements. In the order of the Heteropods, the eyes are very largely developed. Of the Lamellibranchiata, which are acephalous, most are destitute of eyes. In some, however, rudimentary eyes are said to exist; these so-called *eye-spots* are situated, in the Pecten and others, on the margin of the mantle, between the tentacular appendages, and present the appearance of little shining pear-like bodies, supported on short movable pedicles, and having a pigment layer provided with a silvery stratum; sometimes they are arranged singly, at other times, in groups of 20 or 30, close to each other. In the Tunicated Molluscoida, *pigment spots* are found on the central nervous ganglion, but no lens has been discovered in them.

From the preceding account, it appears that in the Molluscous Class, the eye is gradually simplified, in passing from the complex organ of the Cephalopods, through the simpler eyes of the Pteropods, Heteropods, and Gasteropods, to the still more simple eye spots of certain of the Lamellibranchiata; but, in all these cases, a special refractive body or lens is met with, so that perhaps more or less perfect images, at least of *near* objects, are formed, or, as especially occurs in the more simple forms, a mere concentration of luminous rays takes place, at the back of the eye. In the pigment spots of the Molluscoida, however, so far as is known, no lens exists, but merely pigmentary and nervous substance in close conjunction; hence in these animals, sight must be supposed to be reduced to a mere appreciation of light and colour, without any distinction of form whatever.

Amongst Insects, two kinds of eyes are found, the *simple* and *compound*. Usually both occur together, but some insects have only simple, and others only compound, eyes. The *simple* eyes, called *stemmata*, *ocelli*, or *eye-spots*, resemble, in a general manner, the organs of vision in the higher animals, and present the following structures, viz. a minute transparent cornea, close behind which, is a globular lens, resting upon a cup-shaped vitreous humour; on the posterior convex surface of the latter, a nervous filament spreads out, forming a retina; and surrounding the whole, is a choroid coat, which, passing on to the anterior surface of the lens, there forms a sort of pupillary aperture; the colour of the choroid coat, and therefore of the ocelli, varies, but is more commonly dark. The *compound* or *facetted eyes* present quite a different structure. In the common cockchafer, for example, the optic nerve, given off by the supra-œsophageal ganglion, swells into a large segment of a sphere; from this part, an immense number of very short branches are given off,

which spread out, behind a layer of pigment called the *common choroid*, into a membranous expansion named the *common retina*; from this retinal expansion, a multitude of filaments, corresponding in number to the facets of the cornea, are given off, which, after traversing the common choroid, spread out upon a number of hexahedral transparent prisms, covered in front with minute double convex lenses, the so-called *corneal facets* (Straus-Durckheim). The compound eye of the Libellula, or dragon-fly, consists of an immense multitude of very minute pyramidal tubes, the blunted apices of which are set closely together, on the bulbous extremity of the optic nerve; the base of each tube is turned towards the globular surface of the eye, and is invested by a hard facet or corneola, which forms a *meniscus* or *concavo-convex* lens; behind this, is a small cavity filled with an aqueous humour. Each tube is invested by a dark-coloured layer of pigment, surrounding a clear fluid, which occupies the axis of the tube, and is supposed to correspond with the vitreous humour; in front, between the cornea and the vitreous humour, this pigmentary membrane presents a small pupillary aperture. The compound eye consists, therefore, of a combination of numerous minute independent eyes. The number of single eyes entering into the formation of the compound eyes, is, in some insects, very great; thus, in the ant there are said to be 50, in the common house-fly, 8,000, in the dragon-fly more than 12,500, and in the Mordella beetle upwards of 25,000. The compound eyes are usually sessile, and form rounded eminences on the sides of the head, but sometimes they are supported on a pedicle or footstalk. They frequently present a brilliant colour, such as a bright green, or green and purple, or even a pure gold colour. It has been supposed that the simple ocelli of insects are adapted only for very near vision. The mode in which a visual image is formed by the remarkable compound or aggregate eye, is peculiar. Each minute eye must form an image of a corresponding portion of the visual field, for, owing to its tubular shape, and to the fact that it forms a radius proceeding from a convex surface, it seems probable that only those rays, which fall nearly vertically upon the minute corneal facet, can pass down it, whilst the lateral rays are more or less perfectly excluded. The multitude of separate images, like portions of mosaic, must be combined by the animal, into a single picture, for we cannot conceive that it sees objects multiplied. This act of combination must be a sensorial operation, accomplished in the cephalic nervous apparatus of the insect. The images, separate or combined, formed in such an eye, are not inverted from above downwards, or reversed from right to left, as in the Vertebrate eye, but occupy their normal position; there is no decussation of the optic nerves, and none of the great motor nervous columns.

The Orthoptera, Hemiptera, Neuroptera, Hymenoptera, and various other insects, have, in the perfect state, from two to three simple eyes, and also compound eyes; in such cases, the simple eyes are usually placed on the top of the head. In those insects in which simple eyes only exist, these are usually situated on the side of the head. When numerous simple eyes are grouped together into one mass, they form the *conglomerate* or *aggregate* eye. A few insects are destitute of eyes, such as the neuter Termites, and the Claviger beetle. In the greater number of the larvæ of perfect insects, simple eyes alone exist; thus the larvæ of the bee have two simple eyes; in the larvæ of the Dytiscus

beetle, there are six on each side of the head. Some larvæ are destitute of eyes, as those of Hymenoptera.

The eyes of the Myriapoda, like those of all the higher Annulosa, resemble the eyes of insects; they consist, however, for the most part, of conglomerate, i. e. of simple eyes grouped together; compound eyes are more rarely met with, and when they occur, are of large size. The common Millipede (Julus terrestris) has 28 eyes, placed in 7 rows, which form almost an equilateral triangle. Many Myriapoda are blind.

The Arachnida have only simple eyes or stemmata, but these are of very perfect structure; the pupillary aperture of the choroid, is sometimes provided with muscular fibres, which enable it to be contracted. The number of these simple ocelli varies, being only two in the Chelifer and many mites, 4 in the Phalangia and other mites, 6 or 8 in the Araneida, and 10 in the Scorpion. When present in large numbers, they are often of different size in the same animal, and are either closely crowded together on the top of the head, or placed laterally on the cephalo-thorax, or even on the middle of the upper surface of the abdomen. The eyes of spiders are often very bright, and of a sapphire colour; the peculiar glare of the eyes of some spiders and scorpions, depends on the difference in colour between the circumference and centre of the eye, the former part being pale, and the latter dark. The eye of the Tarantula has a bright red centre, and an amber-coloured margin. Many of the lower Arachnida have no eyes.

The Crustacea possess both simple and compound eyes. The simple eyes are never more than two or three in number; in some of the smaller Crustacea, however, as in Daphnia, a number of these are grouped together, forming a conglomerate eye, and are covered by a common cornea; they are, moreover, movable. The compound eyes resemble those of insects; but they are placed at the extremity of movable peduncles, at least in the highest Orders, so that they can be turned in any direction. The corneal facets are usually hexagonal; sometimes, however, they are square, as in the lobster and shrimp. Among some parasitic or fixed Crustacea, as in the Cirrhopods and others, eyes are entirely absent, but, even in these species, they are present in the larval stage.

The eyes in the Annelides are still more simple; they consist merely of an expansion of the optic nerve, covered by a transparent membrane, formed by the cuticle, and having behind it, a layer of black pigment, sometimes perforated in its centre. In some species, a small transparent, spheroidal, refractive, body or lens is met with, as in Alciope, the Leech, the Nereids, and others; but a lens is not always present. The leech, Hirudo medicinalis, has ten eyes, which appear as small dark elevated dots, arranged in a semicircle on the fore part of the head; they have no pupil. The Eunice has four eye-spots on the posterior part of the body; in the Nereis, there are four arranged in a quadrangle on the surface of the head. In a curious worm, named the Polyophthalmus, besides a group of ocelli upon the head, there is found a succession of other smaller ones, arranged in pairs, one on each side of every segment of the long body; all of these eyes have a minute refractive body or lens. In cases where such a lens is wanting, the animals must be restricted to the mere capability of distinguishing light from darkness, and colour

without form. Even where the lens is present, it is doubtful whether any distinct image is formed, except, perhaps, for very near objects.

In the Annuloida, eyespots are seen in the worm-like Scolecida, in the Rotifera, and in a few of the Echinodermata. In the first group, may be mentioned the Planaria and the larval stage of Distoma and Monostoma, but the Entozoa generally, are destitute of pigment spots. Amongst the Rotifera, most species have two ocelli, but in some they are combined into a single spot, resting on the central ganglion of the nervous system, at the fore part of the body. In the Echinodermata, eyespots are seen at the ends of the rays of a few starfishes, and around the lower opening of the alimentary canal in some Echinida.

In a few of the Cœlenterata, pigment spots are present, either destitute of a lens, variously coloured, and placed on the central nervous ganglion, as in Beroe and other allied forms; or provided with a lens-like body, embedded in pigment, as in the red or yellow coloured eyespots found around the borders of the mantle or disc in the Medusa, in immediate contiguity with the so-called auditory sacs, or lithocysts. Nervous filaments probably proceed to them.

In these cases, and in those Annuloida in which such pigment spots, though destitute of a refractive lens, are situated upon the central nervous ganglion, their sensory office can hardly be denied; and, as they occupy positions corresponding to the true ocelli provided with lenses, in other animals, their visual function, however feeble, is placed almost beyond a doubt.

In the Protozoa, pigment spots are only known to exist in certain Infusoria. As no nervous system has been demonstrated in these low unicellular animal organisms, it has been disputed whether in such creatures, the pigment spots are really visual organs. The undoubted influence of light upon these animals, attracting them, for example, to the light side of the vessel in which they are kept, may be owing to a sensibility inherent either in the sarcodous substance of their bodies, or in nervous granules connected with the pigment spots; or, as elsewhere remarked, such apparent attraction may be explained by the incidental action of the heat associated with the light.

END OF THE FIRST VOLUME.

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